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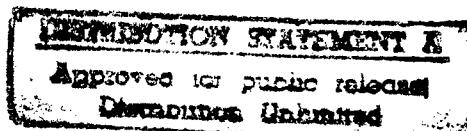
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DREA CR/96/422

BOTTOM CLASSIFICATION BY QTC VIEW NEAR THE DRY TORTUGAS

by
Bill Collins and Brad Prager

QUESTER TANGENT CORPORATION
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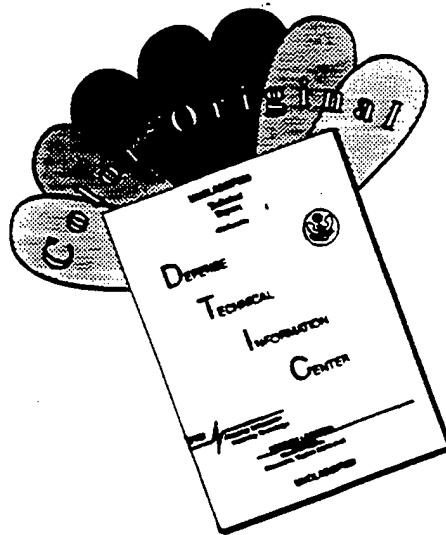


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Scientific Authority

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Abstract

The research described in this report represents an important step forward in the development of seabed classification technology. First, it represents the application of the QTC VIEW technology to a new seabed environment. The data sets analyzed here involve reef seabeds which have not previously been studied. Second, they represent a consistent effort to compare the results obtained by using two different frequencies of sounder over the same seabed type. The results suggest that both 200 kHz and 24 kHz sounders can be used to classify the four bottom types involved in the study. However, it is clear that multispectral seabed classification holds significant potential in situations where, for example, a gravel bedform is overlain by a thin veneer of mud.

Résumé

Les recherches que nous décrivons dans ce rapport représentent une étape en avant significative dans le développement de la technologie pour la classification des lits de la mer. D'abord, elles représentent l'application de la technologie QTC VIEW à un nouvel environnement de lits de la mer. Les ensembles de données analysés ici comprennent des lits de la mer à récifs, que l'on n'a pas étudiés auparavant. Ensuite, nos recherches représentent un effort constant de comparer les résultats obtenus en utilisant deux fréquences de sondeur différentes au-dessus d'un même type de lit de la mer. Les résultats suggèrent que les sondeurs à 200 kHz et à 24 kHz peuvent, tous les deux, servir à classifier les quatre types de fond impliqués dans l'étude. Néanmoins, c'est claire que la classification multispectrale de lits de la mer montre du potentiel significatif dans les situations où, par exemple, un lit de gravier est recouvert d'une couche mince de boue.

1. Introduction

This report is supplied under the terms of a contract managed by the Esquimalt Defence Research Detachment (EDRD) of the Defence Research Establishment Atlantic (DREA), and supplied by Supply and Services Canada. The contract, number W7708-5-0208/01-XSA, involving research into depth dependence of Quester Tangent Corporation's (QTC) seabed classification system and seabed classification from echo soundings acquired in the Dry Tortugas area near Key West, Florida, was completed by March 31, 1996. This report describes research background, methodology, and results of Part 2, Florida Keys data.

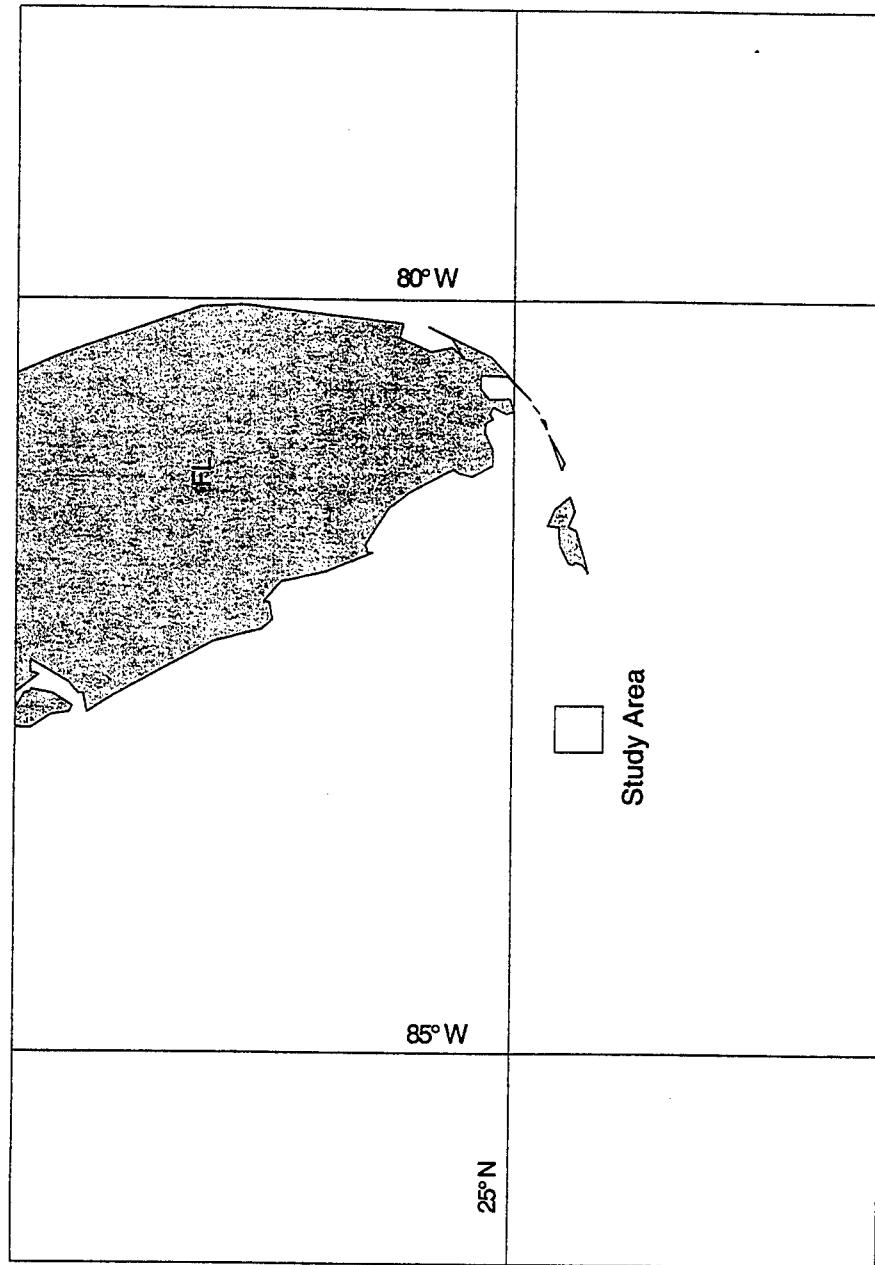
The research described in this report represents an important step forward in the development of seabed classification technology. First, it represents the application of the QTC VIEW technology to a new seabed environment. The data sets analyzed here involve reef seabeds which have not previously been studied. Second, they represent a consistent effort to compare the results obtained by using two different frequencies of sounder over the same seabed type. The results suggest that both 200 kHz and 24 kHz sounders can be used to classify the four bottom types involved in the study. However, it is clear that multispectral seabed classification holds significant potential in situations where, for example, a gravel bedform is overlain by a thin veneer of mud.

Section 2 of this report describes the geological setting and ground truth from the Florida Keys, Dry Tortugas study area (see Figure 1.1). A 3' x 3' grid was surveyed at 1/2' spacing resulting in the acquisition of over 70 line km of acoustic data. A wide variety of bottom information was collected for the work using several vessels, and remote and in-situ measurement techniques. While the ground truth is not evenly spaced over the study area, the ground truth information is among the most detailed available for this type of work to date.

Section 3 describes the seabed classification techniques used to process the acoustic data, and Section 4 describes classification results. Sufficient detail of results is presented on a line-by-line basis to allow the reader to draw conclusions as to the classification accuracy obtained in the study.

Finally, Section 5 presents conclusions and suggestions for further research.

Figure 1.1 Florida Keys, Dry Tortugas Study area ($24^{\circ}35'N$ $82^{\circ}50'W$).



2. Geological Interpretation and Ground Truthing

This section describes the geological setting of the study area and ground truthing available to confirm the seabed classification produced by the QTC seabed classification system.

2.1 Geological Setting

The study area (24°35'N, 82°50'W) is located just south of the Dry Tortugas area at the western leading edge of the Florida Keys (Figure 1.1). The Keys are a series of coral sand cays and exposed limestone reef flats extending westward from the Atlantic coast of Florida along the southern edge of Florida Bay. The cays of the Dry Tortugas are sub-aerially exposed lithified sand shoals. The cays range from 2 to 10 metres above sea level. Much of the coastline consists of mangrove swamps.

The study area is located south of Garden Key in water depths ranging from 5m to 30m. The area is underlain by limestone bedrock which has been dated at 125,000 BP. At 6000 years BP the sea level was relatively lower and a series of fringing reefs were formed in the southwest of the survey area. A relatively quick rise in sea level coupled with a high influx of sediment likely proved hostile to reef growth and may explain why the reefs failed to thrive. Remnants of these fringing reefs can be seen in the survey area. The largest of the three reef flat features trends northeast-southwest and is approximately 1 km wide. The northern and southern extent of the reef flats are beyond the limits of the survey area. The surficial sediments are biogenic and are generally silts and clayey-silts with minor sand and gravel deposits. Sediment distribution is likely controlled by storm deposition and modified by tidal induced circulation.

2.2 Ground Truthing Data and Processing

2.2.1 Ground Truthing

Data from 58 sample sites were used as the basis for the description of the surficial geology (Table 2.1). Full descriptions of the sample site data can be found in Appendix A. The sample sites were positioned using GPS. Sample distribution was patchy with the majority of samples collected within a 1 km radius in the northwest corner of the survey area (Figure 2.1). Data were collected using three vessels, the **Planet**, the **Pelican** and the **Seward Johnson**. Sampling methods included gravity and diver core sampling, and cone



penetrometer and diver-held shear vane measurements. In-situ pressure and shear wave velocities were measured at selected sites. Sidescan sonar and 3.5 kHz sub-bottom profiling surveys were completed in addition to a towed-video survey and still camera photographs. There was no towed-body positioning for the video survey.

Selected samples were analyzed to provide mean grainsize and percent gravel, sand, silt and clay. Physical property analysis was used to provide wet bulk density, grain density, water content, void ratio and porosity. In some cases the physical property analysis along with the velocity measurements provided enough information to calculate the acoustic reflection coefficient.

2.2.2 Map Preparation

A base map for the area was prepared in a GIS (Mapinfo). The reef areas plotted on the base map are from interpreted-sidescan imagery made available to QTC. The interpretation was provided on a facsimile copy; the reef locations were digitized from the facsimile and imported into the GIS. The reef locations must therefore be considered approximate. The sample locations and information were imported into the GIS from the Excel spreadsheets which were provided.

The bathymetry was produced from the acoustic and positioning information provided by the QTC ISAH-S system (see Sections 3.2 - Data Acquisition and 3.3 - Data Pre-Processing). The boat track is plotted in Figure 2.2. The GPS positioning (unfortunately generally not differentially corrected) was processed using QTC's HYPS processing software. Water depths were calculated using QTC's Basic Waveform Processing software. The raw water depths, uncorrected for tide and draft, and not tied to any datum were imported into surface modeling software (Surfer) and gridded using triangulation with linear interpolation. Contours were produced and smoothed using a spline function. These contours were then imported into the GIS. Unfortunately the positioning is not precise enough to produce an accurate bathymetry (QTC software can processes the ISAH-S acoustic data to a depth accuracy of better than 10 cm assuming the sound speed profile is known); however, the relative bathymetry is adequate for the purposes of this paper.

Figure 2.1 Ground truthing locations.

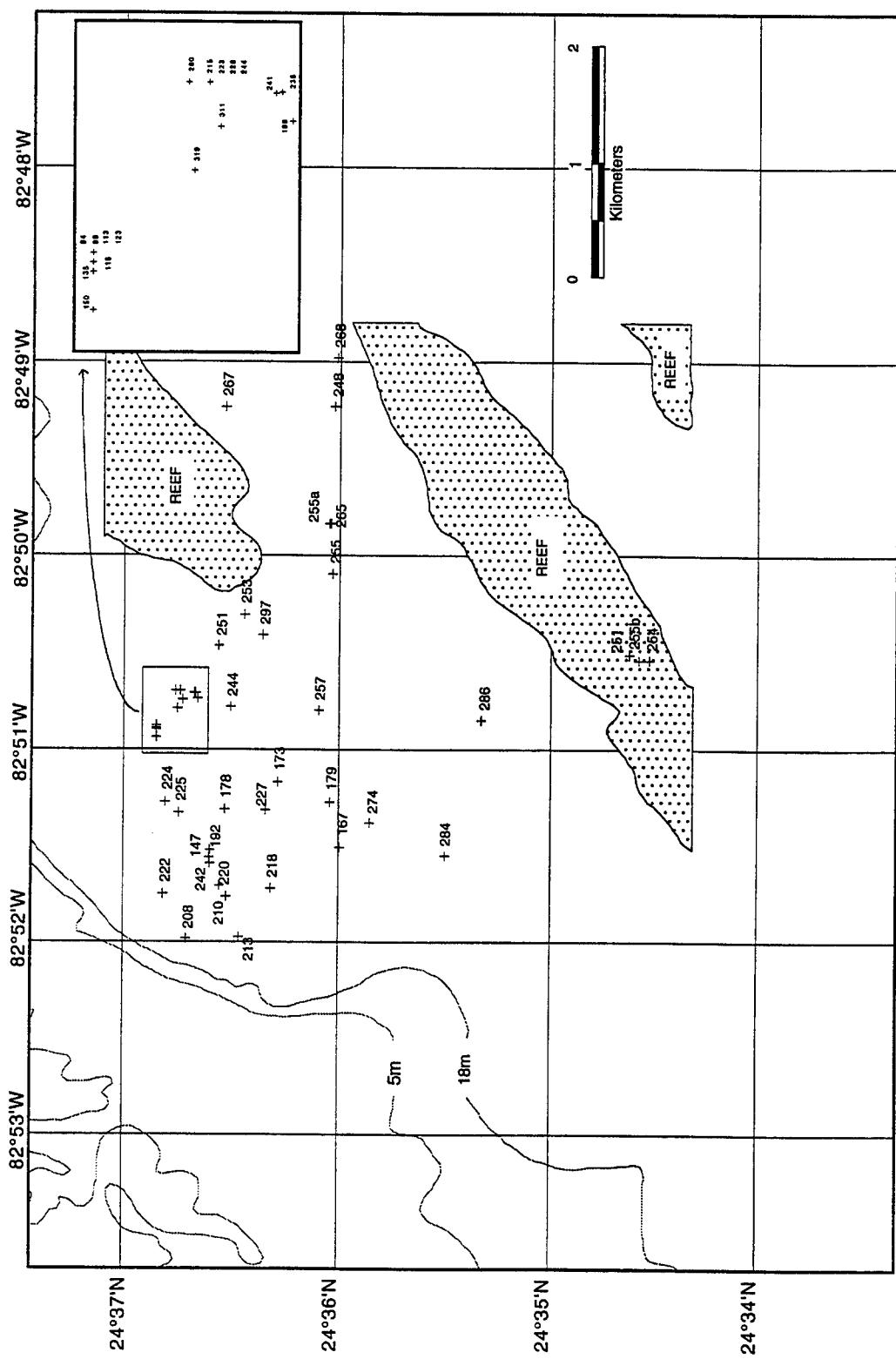
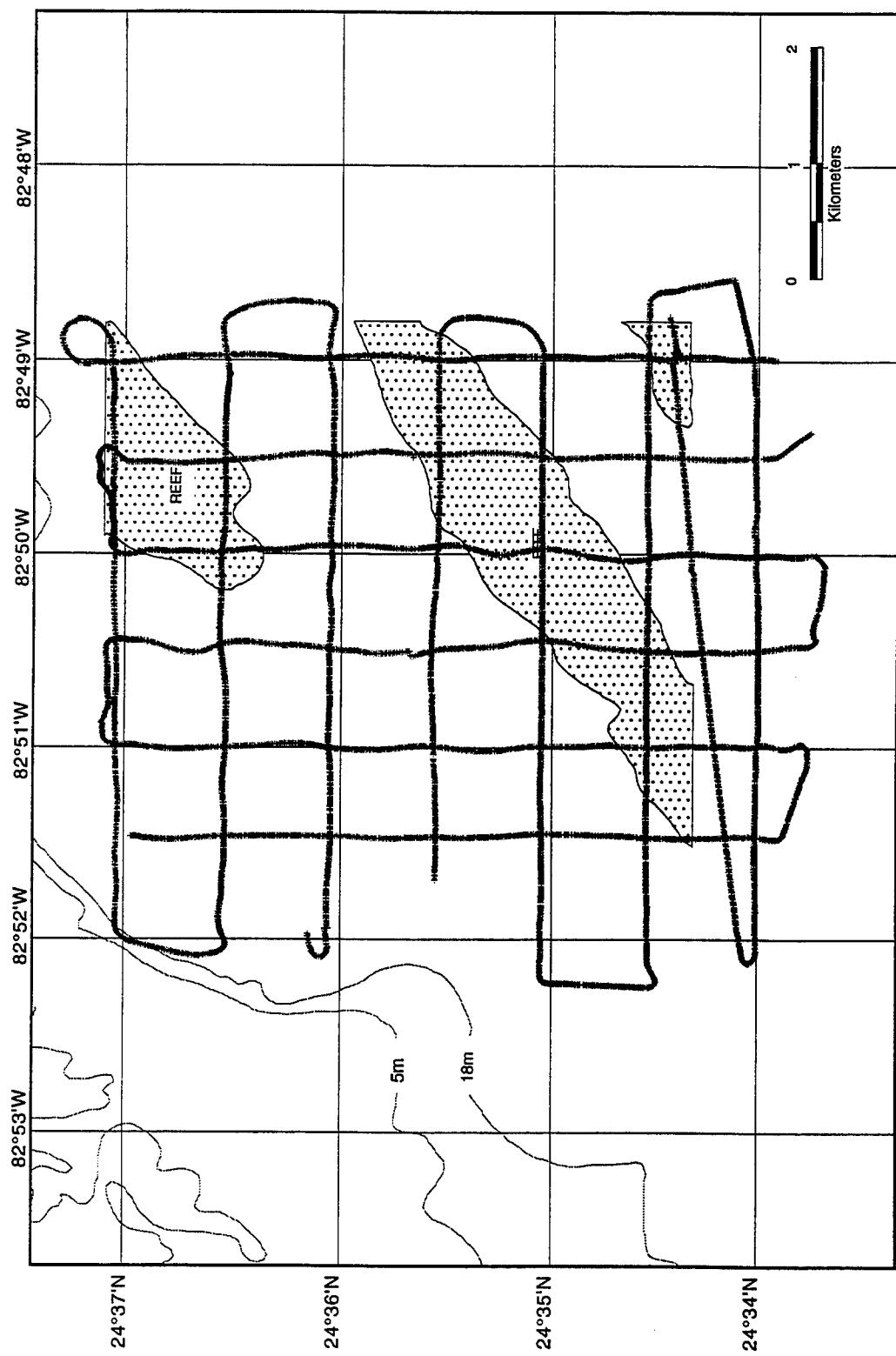


Table 2.1: Compilation of the sediment analysis and in-situ measurements. The grainsize results are from the uppermost section of the cores.

Sample	Type	P-wave vel.	Mean grainsz	% Gravel	% Sand	% Silt	% Clay	Wet Bulk Density	Grain Den.	% Water	Void ratio	Porosity	Refl. Coeff.
147	KW-PE-GC	1596	6.08	0.00	21.56	61.08	17.40	1.68	2.72	58.18	1.58	61.26	0.277
167	KW-PE-GC	1629	5.70	0.45	29.92	52.60	17.02	1.56	2.70	67.13	1.81	64.44	0.254
178	KW-PE-GC		4.42	2.23	39.71	46.97	11.09	1.74	2.71	44.30	1.17	53.93	
203	KW-PE-GC	1626	5.82	4.39	18.20	61.65	15.77	1.75	2.66	42.33	1.10	52.37	0.304
210	KW-PE-GC		6.03	0.58	22.67	56.20	20.54	1.69	2.71	50.24	1.33	57.08	
213	KW-PE-GC		6.42	0.02	13.25	68.56	18.15	1.68	2.74	52.74	1.41	58.49	
218	KW-PE-GC		6.15	0.04	23.60	56.36	19.99	1.54	2.74	75.20		66.76	
222	KW-PE-GC		6.27	0.00	12.31	70.66	17.03	1.71	2.70	47.16	1.24	55.39	
224	KW-PE-GC		5.72	0.18	27.37	56.03	16.42	1.71	2.73	48.29	1.29	56.32	
225	KW-PE-GC	1583	5.92	0.04	31.01	50.89	18.06	1.81	2.71	37.70	1.00	49.94	0.308
227	KW-PE-GC		5.64	0.39	28.98	55.74	14.87	1.69	2.73	51.12	1.37	57.84	
208	KW-PE-GC							1.79	2.73	40.81	1.09	52.15	
220	KW-PE-GC	1610						1.55	2.66	70.03	1.82	64.48	0.243
179	KW-PE-GC							1.65					
285	KW-PE-GC							1.91					
113	KW-PL-DC	1523	6.91	0.00	19.71	43.07	37.21	1.48				73.87	0.196
173	KW-PL-DC	1528	6.50	0.05	31.13	36.86	31.95	1.57				69.03	0.226
192	KW-PL-DC	1533	6.73	0.00	28.47	38.74	32.78	1.55				70.05	0.221
198	KW-PL-DC	1533	6.75	0.00	31.00	34.25	34.75	1.53				70.98	0.215
215	KW-PL-DC	1544	6.03	0.12	38.84	32.14	28.90	1.66				64.49	0.257
223	KW-PL-DC	1523	7.53	0.00	20.94	34.96	44.10	1.51				72.46	0.206
244	KW-PL-DC	1523	7.31	0.00	14.99	40.96	44.05	1.55				69.75	0.218
263	KW-PL-DC	1651	1.00	0.90	91.11	5.26	2.73	1.99				45.81	0.333
236	KW-PL-DC-IA	1537											
241	KW-PL-DC-IA	1545											
242	KW-PL-DC-IA	1544											
251	KW-PL-DC-IA	1541											
253	KW-PL-DC-IA	1558											
255	KW-PL-DC-IA	1581											
257	KW-PL-DC-IA	1551											
265	KW-PL-DC-IA	1672											
266	KW-PL-DC-IA	1576											
274	KW-PL-DC-IA	1573											
280	KW-PL-DC-IA	1536											
284	KW-PL-DC-IA	1567											
286	KW-PL-DC-IA	1600											
288	KW-PL-DC-IA	1697											
290	KW-PL-DC-IA	1708											
248	KW-SJ-GS-XB		Med sand										
251	KW-SJ-GC-XB		Coral, Rock										
254	KW-SJ-GS-XB		Muddy										
255	KW-SJ-GC-XB		Fine Sand, Med sand										
244	KW-SJ-PCT		Soft fine-sandy silt										
265	KW-SJ-PCT		Silty-sand										
267	KW-SJ-PCT		Silty-sand										
297	KW-SJ-PCT		Firmer sandy-silt										
319	KW-SJ-PCT		Soft clayey-silt sized (plastic-like)										
178	KW-SJ-GC							1.62					
311	KW-SJ-GC								1.92				
326	KW-SJ-GC								1.84				

Figure 2.2 Boat Track.



2.3 Results

2.3.1 Relative Bathymetry

The relative bathymetry over the survey area is shown in Figure 2.3. The seabed exhibits approximately 11m of relief over the survey area. There is a general shallowing trend from southeast to northwest; the seabed is relatively flat in the northern section and between the reef areas. The most prominent bathymetric features are pinnacles which occur in the southern section. A 4m pinnacle is associated with the southern end of a reef flat area. This feature is about 100m x 400m in size with the long axis oriented parallel to the central axis of the flat reef area. A series of three smaller pinnacles of approximately 3m relief are aligned parallel to the central axis of the main reef and appear to be associated with the small reef flat area to the southeast. Unfortunately this could not be confirmed as the pinnacles occur beyond the southern limit of the sidescan data which were provided. It is tempting to interpret these pinnacles as modern reef colonies because old reef flats often provide a stable platform conducive to reef growth.

2.3.2 Sediment Texture

Figure 2.4 shows sediment type for selected samples. Two samples at the southern end of the central reef flat area were described; one was silt and the other was coral, rock. The coral, rock sample is consistent with the interpreted reef flat location. The sample of silt may have been collected from deposits of fine sediment which accumulate in the interstitial voids in a reef flat. Alternatively, the coral to silt transition between the two samples could indicate that the reef flat boundary as interpreted from the sidescan sonar is inaccurate.

From sample 248, located at the north end of the central reef flat, the sediments become progressively finer towards the northwest, ranging from medium sand through silty sand, sandy silt and clayey silt. The more sandy samples were collected from the broad shallow area located between the north and central reef flats. This area may represent a higher energy environment.

Most samples show little gravel in the sediment. Apart from one site corresponding to a bathymetric high at the north end of the central reef flat the gravel content in the sediments seems to be highest at the head of the northeast-trending trough at the west of the survey area. The percentage of sand in the seabed sediments is at a maximum of 90% to the north of the central reef flat. The average percentage of sand in the rest of the samples was about 24%. There

is a trend towards a decrease in the percentage of sand towards the shallower water depths to the northwest. The percentage of silt increases to the northwest. The area adjacent to the western edge of the northernmost reef flat contains the highest percentage of clay. Figures 2.5 - 2.8 show the percentages of gravel, sand, silt and clay.

Table 2.2 is a compilation of the percentage of gravel size fraction in the sediments to 60 cm below the seabed. This table shows a broad increase in the percentage of gravel with depth. Note the significant increase in the amount of gravel at 40 cm to 60 cm below the seabed.

Sample	2 cm	10 cm	20 cm	30 cm	40 cm	50 cm	60 cm	2-30 cm
147	0.00	0.10	10.00	2.20	3.80	3.70	4.50	3.08
167	0.50	3.20	2.30	4.50	3.90	7.90	4.70	2.63
178	2.30	0.67	0.68	1.51	1.31	3.06	1.96	1.29
203	4.40	25.30	13.80	10.00	8.40	5.10	0.08	13.38
210	0.58	1.79	1.55	1.25	6.46	3.19	4.37	1.29
224	0.18	0.50	0.81	1.59	1.18	1.39	2.83	0.77
113	0.03	0.06	0.36	0.54				0.25
173	0.05	0.39	2.81	0.76				1.00
192	0.69	0.00	0.00	0.00				0.17
198	0.00	0.10	0.16	0.70				0.24
244	0.00	0.18	0.00	0.38				0.14

Table 2.2: Percent gravel at increasing core depth for selected sites.

2.3.3 Video Imagery

Approximately 45 minutes of video imagery was analyzed. One video transect across the north area of the central reef flat showed a relatively flat seabed with little relief. The surficial sediments consist of a veneer of fine to medium sand over a reef flat. Small cobbles of apparent reef debris lay on the surface of the reef flat in some areas. The reef flat exhibits a rough surface texture with cavities on the order of 10 cm in diameter.

A second video transect from an area to the west of the northern reef flat was also analyzed. The seabed is again relatively flat with little surface roughness. The surficial sediments appear to consist of very fine grained material. A preponderance of flora on the seabed is evident.

Figure 2.3 Relative bathymetry of survey area. Note that depths are below transducer and are not corrected for draft, tide, datum. Sound speed of 1525 m/s was used.

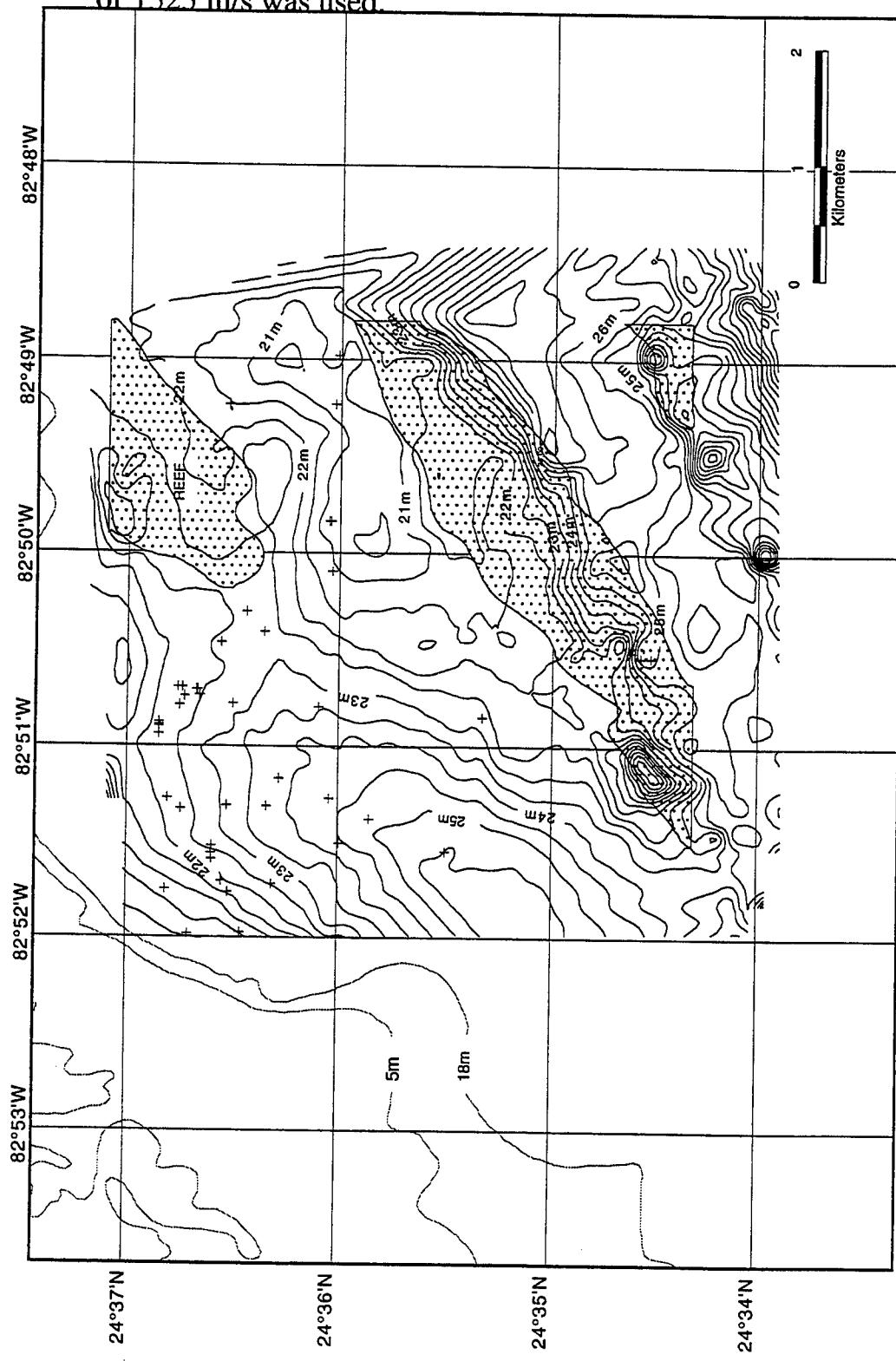


Figure 2.4 Seabed type at selected ground truth sites.

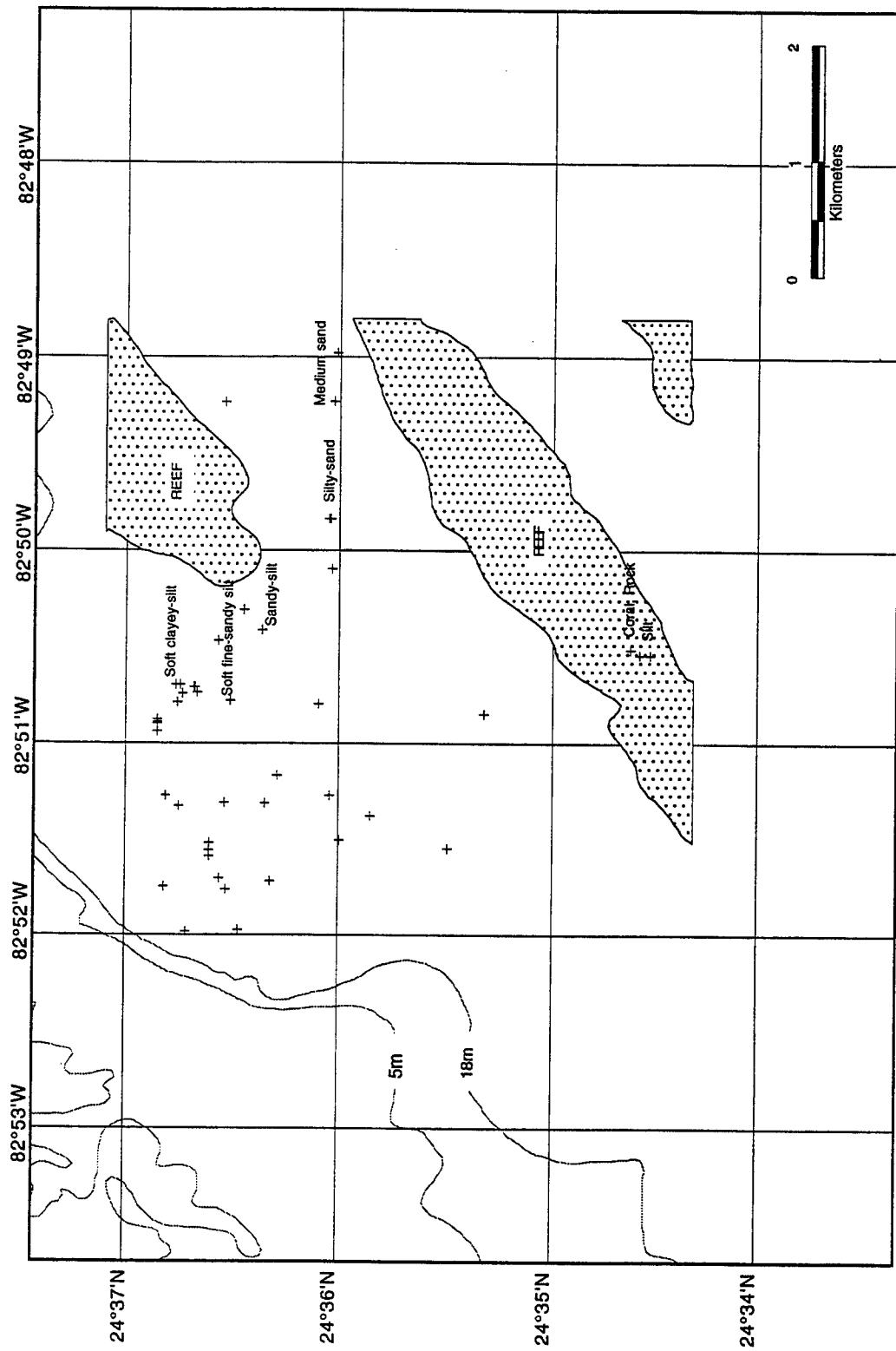


Figure 2.5 Percentage gravel at selected ground truth sites.

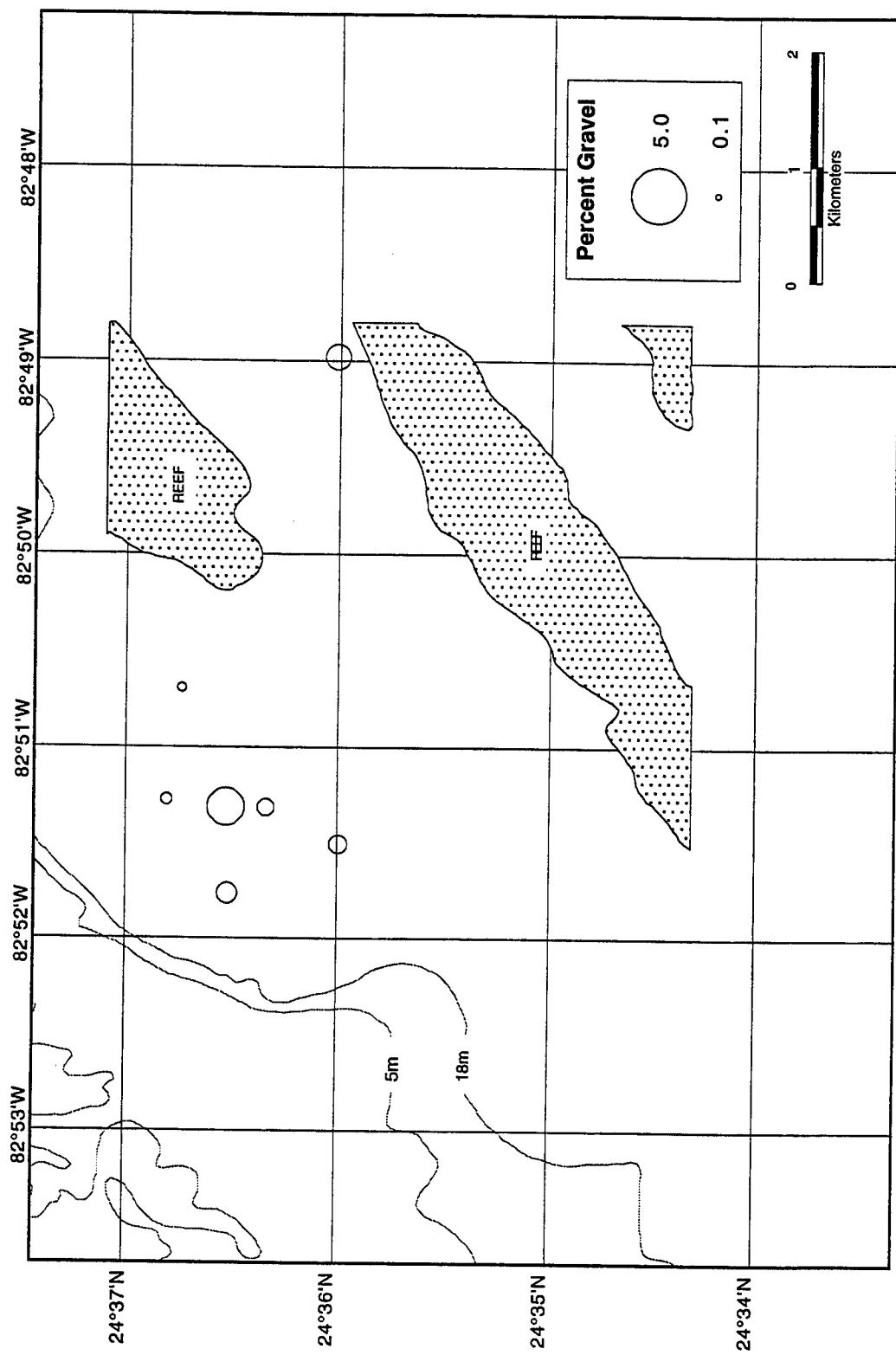


Figure 2.6 Percentage sand at selected ground truth sites.

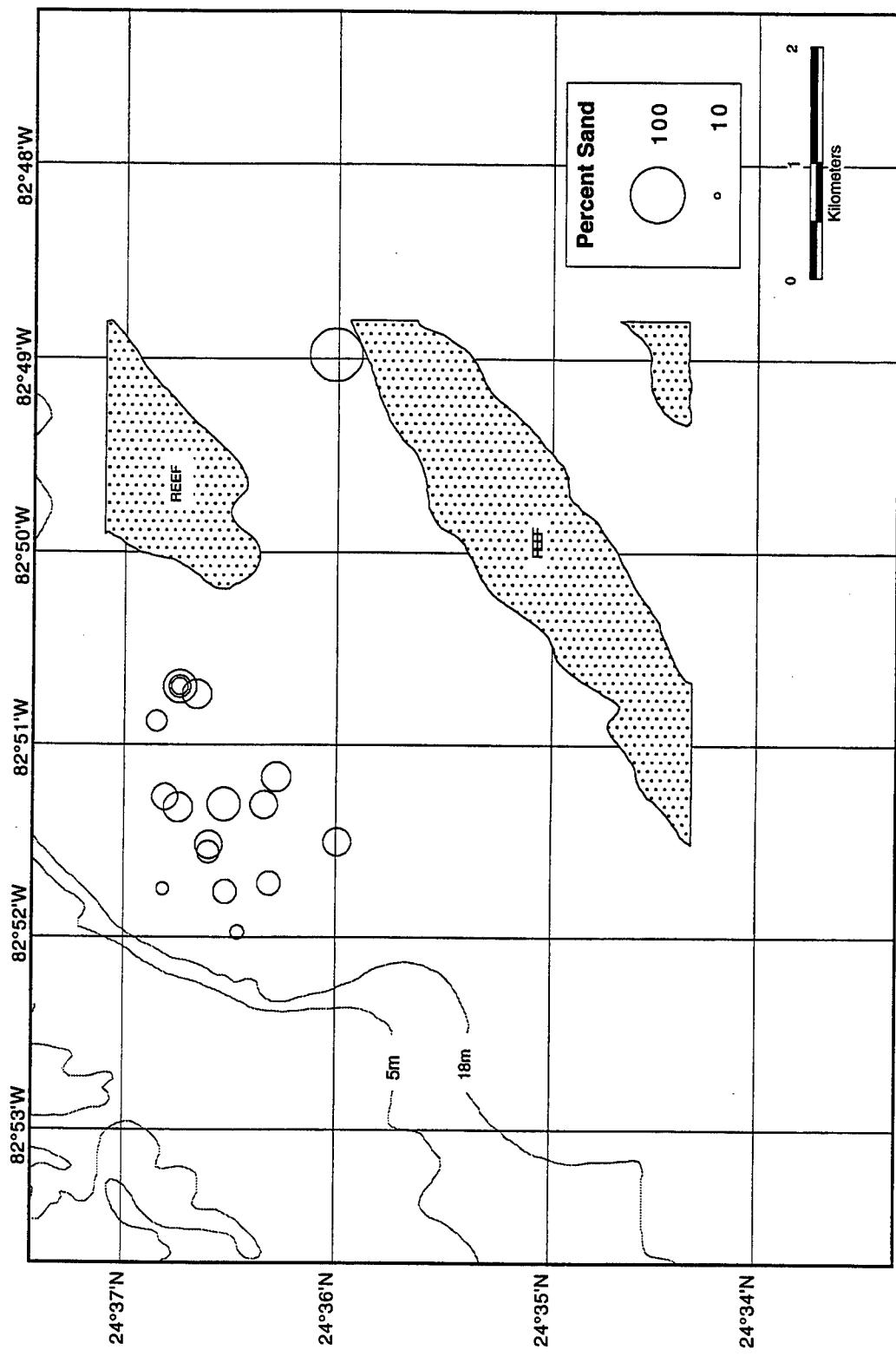


Figure 2.7 Percentage silt at selected ground truth sites.

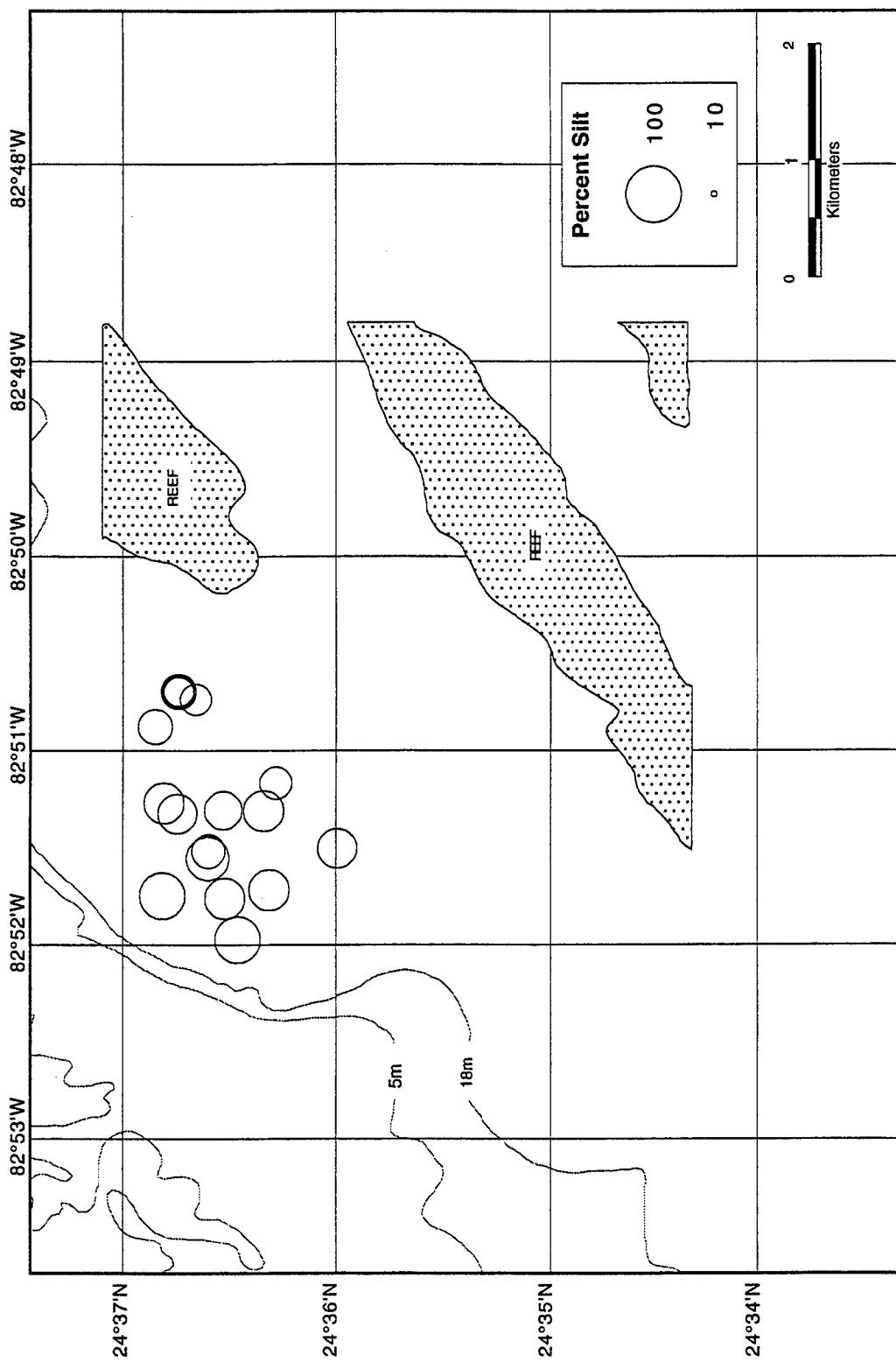
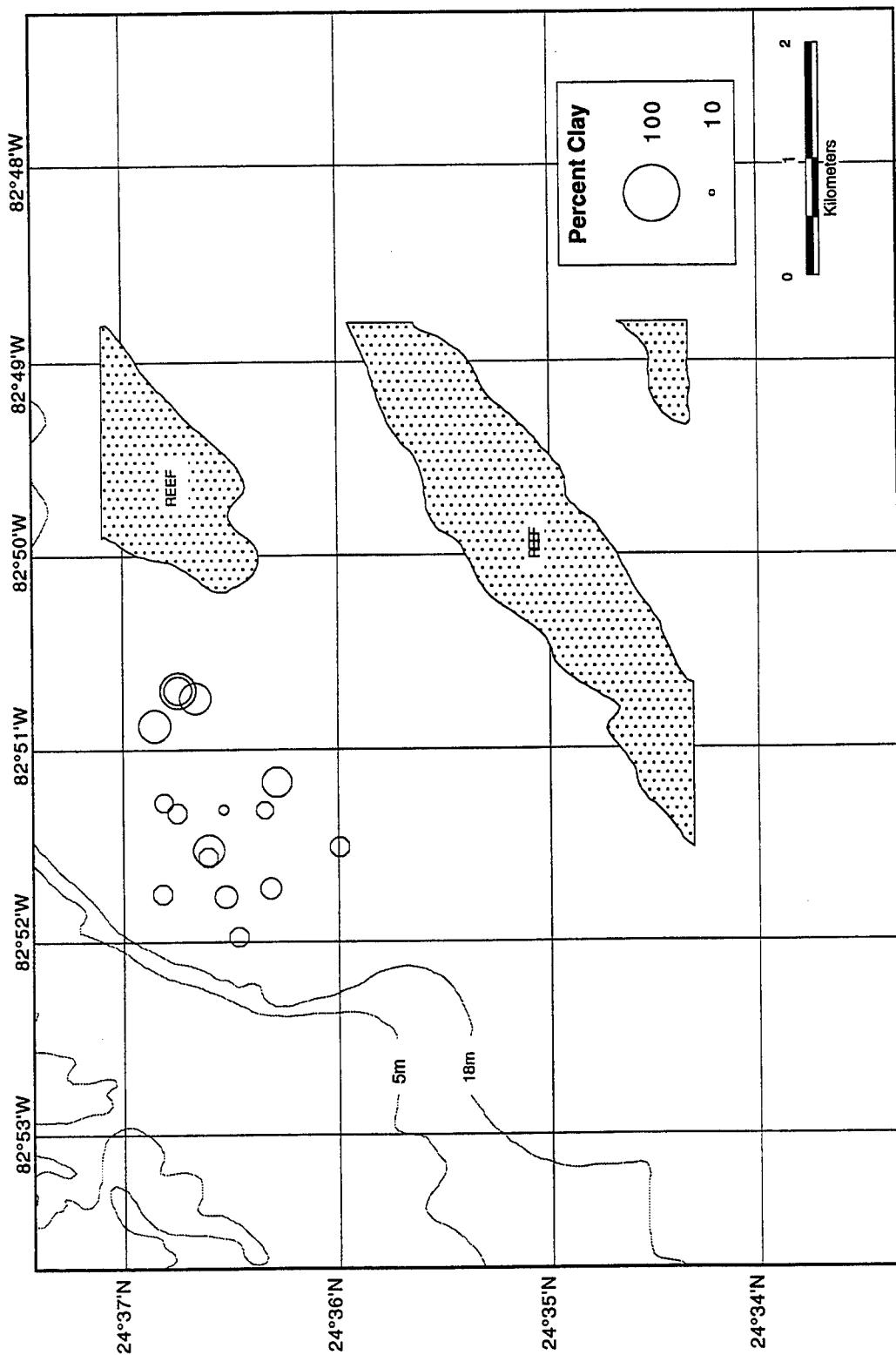


Figure 2.8 Percentage clay at selected ground truth sites.



2.4 Discussion

The very patchy nature of the sampling makes a detailed analysis of the sediment distribution difficult. The dominant component of the geology within the survey area are the reef flats which have likely greatly influenced the Holocene sediment deposition. The reef flats are essentially sediment free except for some reef debris which cannot be transported except under extreme conditions.

In a fringing reef environment material is eroded from the seaward edge of the reef and transported over the reef crest and deposited in backreef or lagoonal areas. Tide-induced circulation patterns in backreef areas tend to transport material in a shore-parallel direction until the material is flushed from the system through a reef passage or by deposition on beaches through constructional wave activity. In pre-Holocene times when sea level was lower a higher energy environment existed and may account for the increase in gravel content with depth. During the last 6000 years sediment deposition has likely been the result of material being transported from the north and northeast. As there appears to be few modern reef organisms producing sediment in the area the existing sediments will be degrading and thus will become fine grained through time. It is to be expected that the finer material will be deposited in hydrodynamically quiet areas such as small basins or areas protected by bathymetric highs. This may account for sediments becoming increasingly finer grained at the western edge of the northern reef flat which is protected to the east by the platform situated between the central and northern reef flat. The coarse material at the north end of the central reef flat may be the result of being located on a topographic high. Also, the actual boundary of the reef flat as determined by the sidescan sonar may not be accurate. The relatively high percentage of gravel in the central portion of the survey area appears to correlate with the central axis of the northeast trending trough and may reflect higher energy conditions due to tide-induced circulation patterns.

In summary the surficial geology can be broadly subdivided into reef flats and shallow shelf sediments. The shelf sediments appear to become coarser with subsurface depth especially to the northwest. The shelf sediments show relatively little variability except for coarser grained material at the northern end of the central reef flat, the axis of the northeast trending trough, and to the west of the survey area. The sampling bias prohibits a more rigorous classification.

2.5 Conclusions

Data from a total of 58 sample sites augmented with sidescan sonar data and video imagery provides the following interpretation of the surficial geology of the survey area:

1. The bathymetry shows a broad shallowing trend to the northwest. Total relief in the area is approximately 11m. Bathymetric features include a northeast trending trough to the west and a series of pinnacles, 3m and 4m in height, in the southern portion of the survey area.
2. Sediment textural analysis indicates that the majority of sediments can be classed as silts and clayey silts except for samples located at the east central portion of the survey area and along the axis of the northeast trending trough to the west of the survey area.
3. There appears to be an increase in grainsize with subsurface depth, especially in the northwest.
4. The surficial geology can be classified as two distinct units: reef flat and shallow shelf sediments. While there appears to be some variability in grainsize the patchy nature of the sampling site distribution prohibits a more rigorous classification.

3. Classification Processing

3.1 Procedure

An acoustic pulse impinging on a seabed is reflected and scattered by both the interface between the water and the seabed and from volume inclusions within the seabed. The returned echo pulse is shaped by the seabed roughness and geoacoustic properties. We make use of the echo shape in order to perform a seabed classification.

First, we generate a great number of shape parameters, currently 166, from each echo. We cannot easily visualize or process so great a number of parameters, but fortunately most parameters carry limited information or redundant information. This means that for a collection of echoes the variance of any individual parameter is small (limited information) or the covariance of any individual parameter with the other parameters is small (redundant information). Second, we use principal component analysis to determine which parameters carry information and extract these parameters. Finally, we analyze these extracted parameters using either supervised or unsupervised classification techniques.

Preprocessing is performed prior to echo shape analysis. First, the seabed echo is located (bottom pick). Next, an ensemble of consecutive echoes is assembled. Each echo in the ensemble is aligned, an average computed, and a single output ping generated. Finally, echo pulse contractions or dilations caused by altitude changes are removed from the average ping.

Features related to the shape of the echo are extracted from the preprocessed ping. We call this collection of features the full feature vector. Our current implementation produces 166 feature vector elements from five algorithms: a histogram of the distribution of the amplitudes in the echo; quantiles of the distribution of the amplitudes in the echo; integrals of the amplitudes to various times in the echo and ratios of these integrals; Fourier spectrum amplitude coefficients; and wavelet coefficients.

Full feature vectors from a variety of seabed types are then used in a principal component analysis. A covariance matrix of dimension 166×166 is produced and the eigenvalues and eigenvectors are calculated. Eigenvectors are a set of orthonormal basis vectors spanning the covariance matrix which can be used in conjunction with the eigenvalues to account for the energy in the covariance matrix most rapidly in a least-squares sense. We have determined that with only 3 out of 166 eigenvectors we can typically account for over 95% of the covariance produced from several thousand pings spanning a wide variety of seabed types. We therefore use the eigenvectors corresponding to the three largest eigenvalues

as weights to reduce the 166 full feature vector elements to a reduced feature vector of 3 elements - features 1, 2, and 3. Features 1, 2, and 3 are the elements of the reduced feature vectors and correspond to the directions associated with the largest, second largest and third largest eigenvalues respectively.

The principal component analysis provides us with a set of reduced feature vectors which contain most of the covariance energy. Since the covariance within the same seabed type is less than the covariance between different seabed types, we expect the reduced feature vectors to be clustered around locations in reduced feature space corresponding to a seabed type. Two general methods of determining the statistics (mean and covariance) of the locations around which clusters occur are available. Note that the covariance of a cluster describes the orientation and size of a cluster in reduced feature space and is not related to the covariance between pings used by the principal component analysis. First, the statistics of each set of reduced feature vectors for each seabed type can be calculated (supervised classification); or second, an assumption about the distribution of points within a cluster can be made and then the location, size, and number of clusters can be adjusted and a chi-squared statistic can be used to determine whether the adjustment has resulted in a better or poorer fit to the assumed distribution (unsupervised classification). Supervised classification is most appropriate if ground truthing exists and known "acoustic signatures" can be assigned to each seabed type. Unsupervised classification is most appropriate where there is little or no ground truthing and therefore no representative echoes from a seabed type can be located and used to determine the acoustic signature. In this case, the clustering analysis will identify acoustic regimes - areas which have the same echo shape characteristics - thus allowing classification into areas of like and unlike echo shapes.

Once the statistics of the clusters corresponding to the various seabed types or acoustic regimes have been determined, classification is made by determining to which cluster any new ping's reduced feature vector most likely belongs.

3.2 Data Acquisition

An ISAH-S acoustic data acquisition system was used to log the following data:

1. Simrad EA300P 200 kHz echo sounder waveforms
2. Raytheon DSF6000 24 kHz echo sounder waveforms

The waveform data were obtained from a post-detection point in the echo sounders and therefore represent the envelope of the time-varying gain (TVG)

corrected signal at the transducer. The transducer specifications are not known but are believed to be in the range of 10° beamwidth for the 200 kHz sounder and 20° beamwidth for the 24 kHz sounder. Pulse lengths were 0.1ms (200 kHz) and 0.2ms (24 kHz). The waveform envelopes were sampled at 20 kHz providing a possible bandwidth to Nyquist of 10 kHz. Actual data bandwidth is only several kHz in both frequency cases. Data were logged to Exabyte 8mm helical scan tape. Examples of 200 kHz and 24 kHz waveforms are shown in Figures 3.1 and 3.2.

An ISAH-HYDAS hydrographic data acquisition system was used to log the GPS position (GPS manufacturer is unknown). Unfortunately the differential link operation was intermittent so the positioning is only generally accurate to SA performance (<100 m). Data were logged to quarter inch cartridge (QIC) DC6150 streamer tapes.

Figure 3.1 200 kHz waveforms.

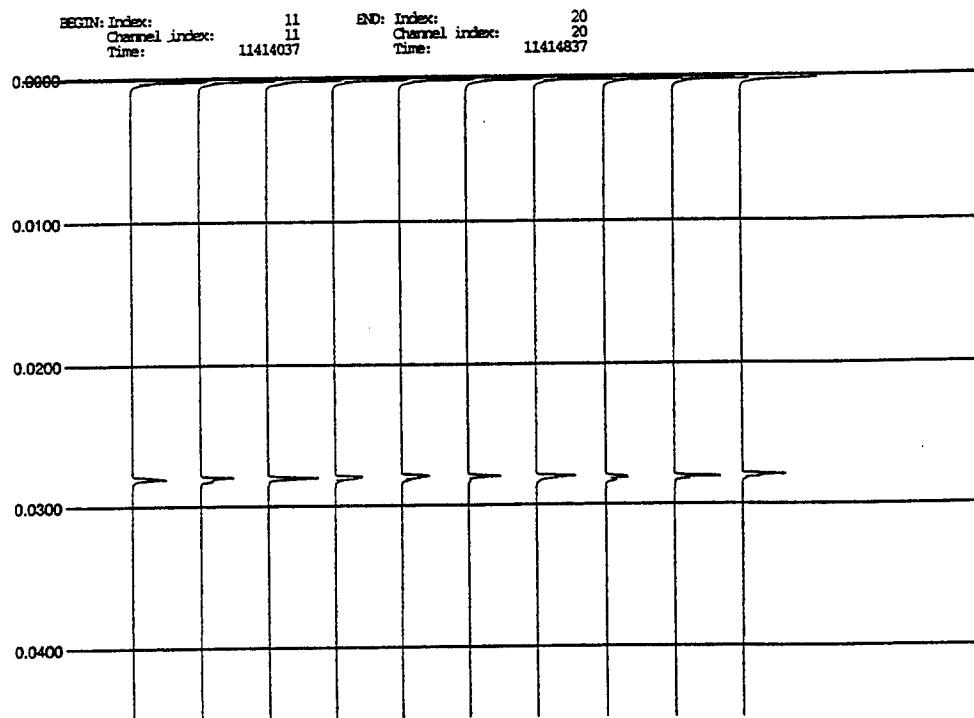
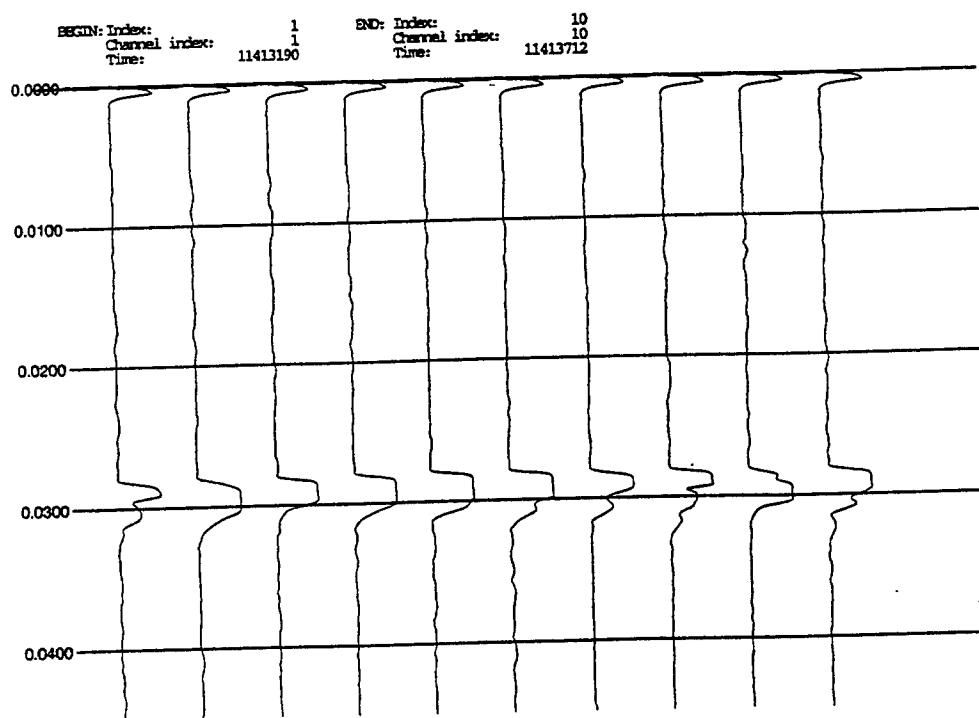


Figure 3.2 24 kHz waveforms.



3.3 Data Pre-processing

Positions were processed using QTC's HYPS processing software. This involved downloading the raw GGA records from the streamer tapes, editing out obviously bad points, and filtering the remaining positions with a Kalman filter. HYPS outputed a position/time table in ASCII format.

The acoustic waveforms were prepared for seabed classification by applying the following processing steps:

1. The waveforms (traces) were downloaded from 8mm tape to disk for more rapid access. Over the survey area more than 44,000 (200 kHz) and 70,000 (24 kHz) waveforms were acquired.
2. The seabed (bottom) was tracked and the water depth used to produce the relative bathymetry figure.
3. A 5-fold stack (averaging) of the traces was performed. Prior to averaging the bottom picks of all traces are aligned to reduce smearing introduced by ping-to-ping depth variations. The ping rates were 1.1 Hz (200 kHz) and 1.8 Hz (24 kHz) and vessel speed was approximately 2 m/s. Therefore the 5-fold stack represents a horizontal separation of approximately 9m at 200 kHz and 5.6m at 24 kHz. The stacking was not rolled along (moving average) therefore the data were spatially decimated: every 5-fold stack was output at 200 kHz; every other 5-fold stack was output at 24 kHz. Total number of traces were therefore 8800 at 200 kHz and 7000 at 24 kHz. These trace densities represent one averaged trace at approximately every 10m along track. Water depth below transducer for the survey area averages about 25m; this means that the acoustic footprint sizes (-3dB) are about 4m at 200 kHz and 9m at 24 kHz. The output trace spacing of 1 trace per 10m represents only 1-2 times the acoustic footprint size and therefore does not seriously degrade the possible spatial resolution.
4. Depth effects are removed by normalizing all echoes to a constant virtual depth. The differential depth effect is not large for these data as water depth is reasonably constant.
5. The echo shape is analyzed using the 5 algorithms described in Section 3.1 above. Each echo is characterized by 166 features.

6. Principal component analysis is used to reduce the 166 full feature vector to 3 principal components, the reduced feature vector consisting of Q1, Q2, and Q3.

3.4 Unsupervised Classification

Unsupervised classification means that the classes are automatically chosen by the system using a Chi-squared criteria. For the unsupervised classification the principal component analysis was run on every 10th trace processed by steps 1-5 in Section 3.3 above. The 24 kHz and 200 kHz reduced features were analyzed separately.

The unsupervised clustering program assumes that the reduced feature vectors cluster around the various bottom types. Each bottom type therefore can be represented by a location in reduced feature vector space (Q1, Q2, Q3 space) and a hyperellipse representing the 1 standard deviation surface of the cluster. If we assume that the distribution of points within a cluster is Gaussian, we can adjust the size and orientation of the hyperellipse enclosing the points until the Chi-squared fit to a Gaussian is minimized. If the Chi-squared fit cannot be reduced to the number of degrees of freedom minus 1, in this case 1, the cluster is split into two clusters and the process continued.

In this way both the 200 kHz and 24 kHz can be clustered into 4 different classes. By inspection of the location of these 4 classes with the ground truthing described in Section 2 above, the following class descriptions were chosen: silt, sand/gravel, reef 1, and reef 2. Reduced feature vectors in Q1, Q2, Q3 space and associated classes for the two different frequencies are plotted in Figure 3.3 and 3.4.

3.5 Supervised Classification

Supervised classification defines classes based on areas of a known bottom type. Feature vectors from these known areas are generated, reduced using principal component analysis, and the class descriptions are calculated for each known bottom type. Unfortunately, ground truthing for the survey area was insufficient to perform a good supervised classification. The original intent was to augment the unsupervised classification classes with any additional known classes; however, the ground truthing quality on the survey lines is inadequate to do this. The positioning of the acoustic and ground truthing data must be of high quality and must coincide and the ground truthing itself must be accurate to allow supervised classification. As processing of the ground truthing from the survey area becomes available it may be possible to augment the unsupervised results.

Figure 3.3 200 kHz Cluster Plot.

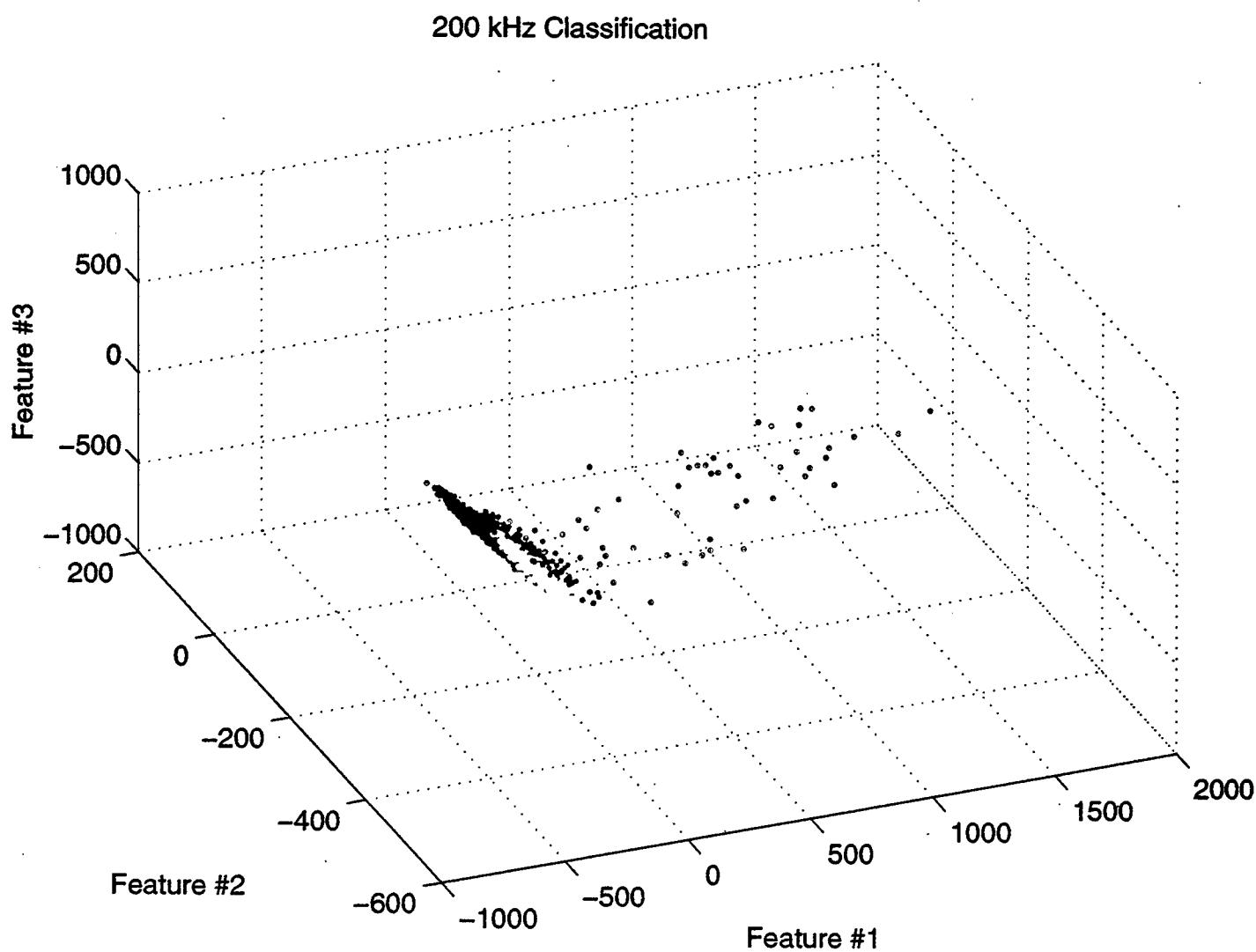
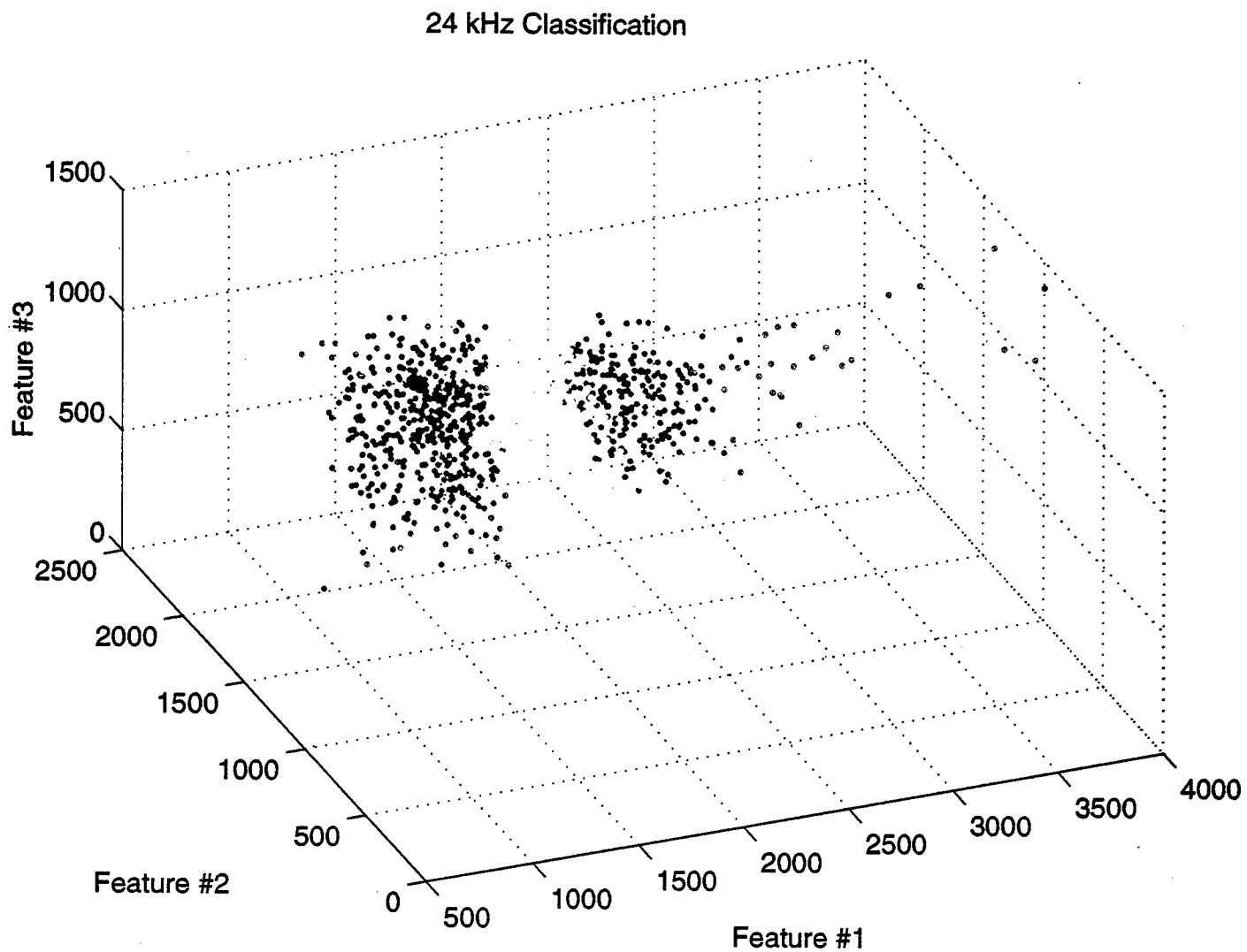


Figure 3.4 24 kHz Cluster Plot.



4. Classifications Results

Maps showing the classification results are presented in this section. Discussion of results is deferred to Section 5. Two types of presentations are made for each frequency: first, trackplot maps are shown with track location colour coded by bottom type; and second, proportional composition plots for each frequency are presented. This section presents proportional composition plots of the entire survey area on one plot; proportional composition plots made on a trackline basis are shown in Appendix B.

Two types of trackplots are shown for each frequency. The first trackplot shows all four bottom types as different colours, the second trackplot plots the sand/gravel, reef 1, and reef 2 classes as all the same colour. The two colour trackplots show the effect of echo sounder frequency more clearly than the four colour plots.

The proportional composition plots are generated by taking an ensemble of 20 successive classifications and outputting the number of each class within the ensemble. These plots are useful because they show that the seabed is not generally homogenous and show how transitions between various bottom types occur. The individual trackline plots shown in Appendix B are generated from ensembles of 10 traces.

4.1 Classifications

Figures 4.1 - 4.4 show the trackplots described above. Figures 4.5 - 4.6 show the proportional compositions of the two frequencies.

These results are discussed in Section 5.

Figure 4.1 Classification of 200 kHz echo sounder data.

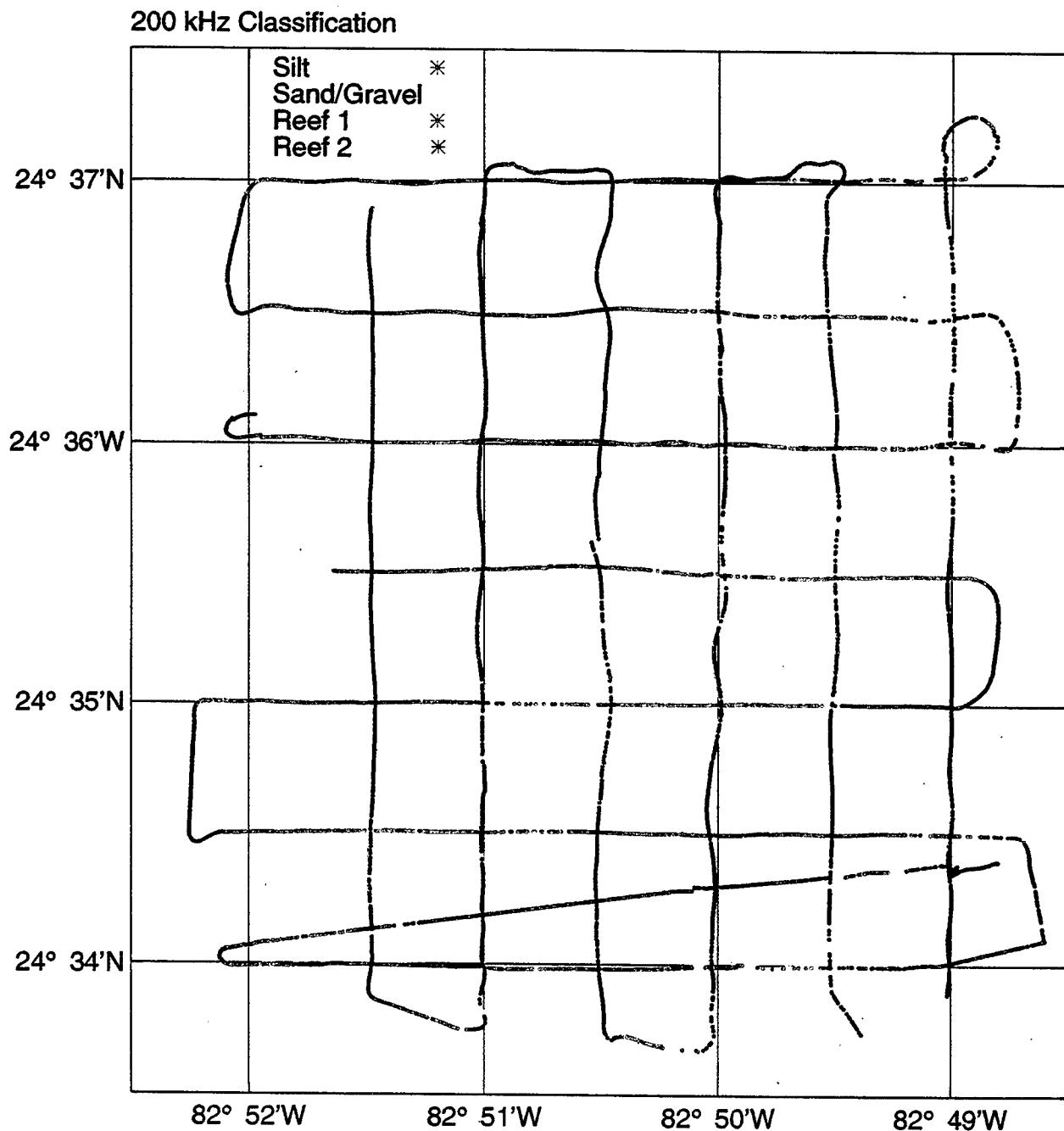


Figure 4.2 Classification of 24 kHz echo sounder data.

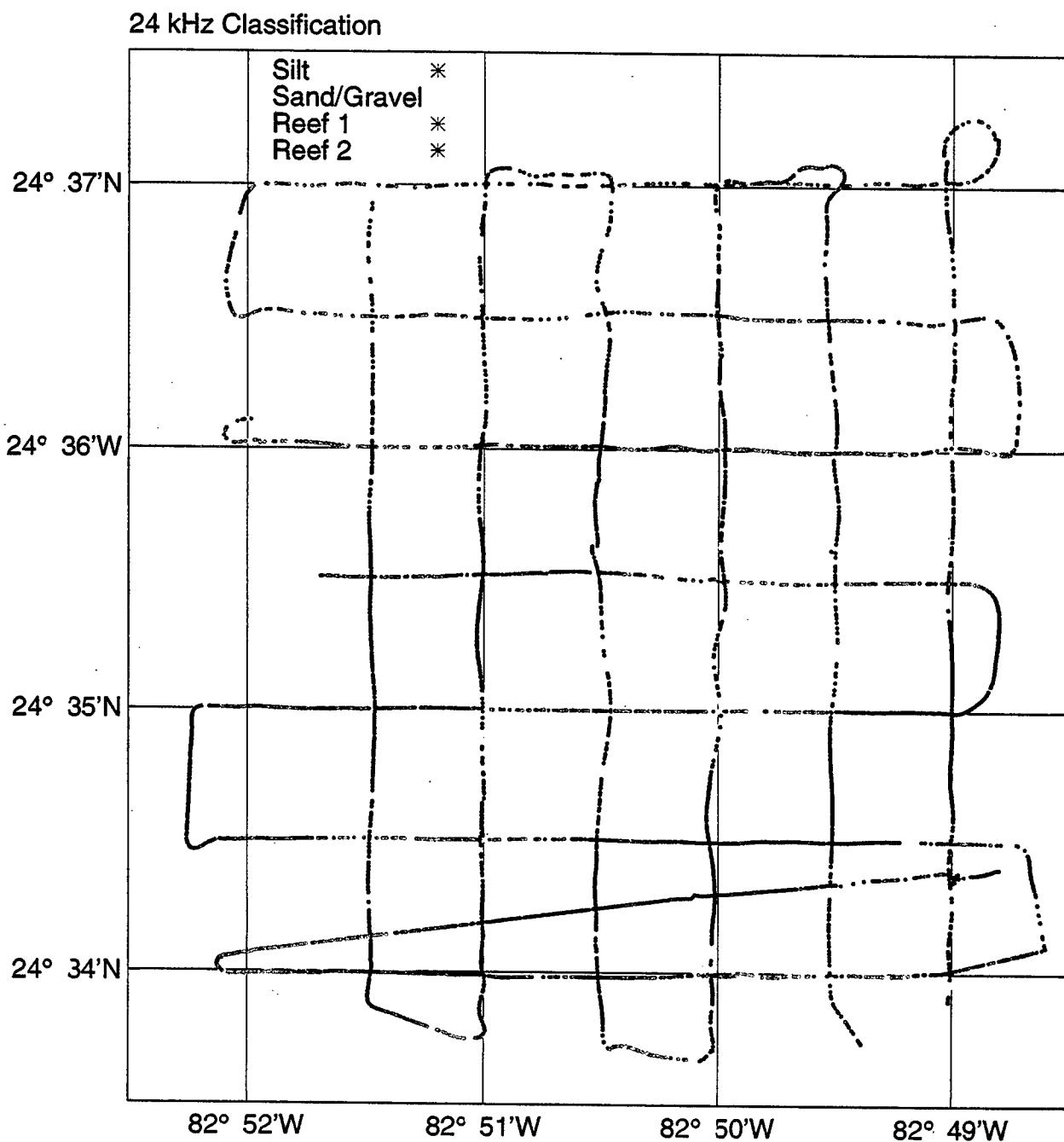


Figure 4.3 Classification of 200 kHz echo sounder data. Classes sand/gravel, reef 1, and reef 2 are all plotted as yellow.

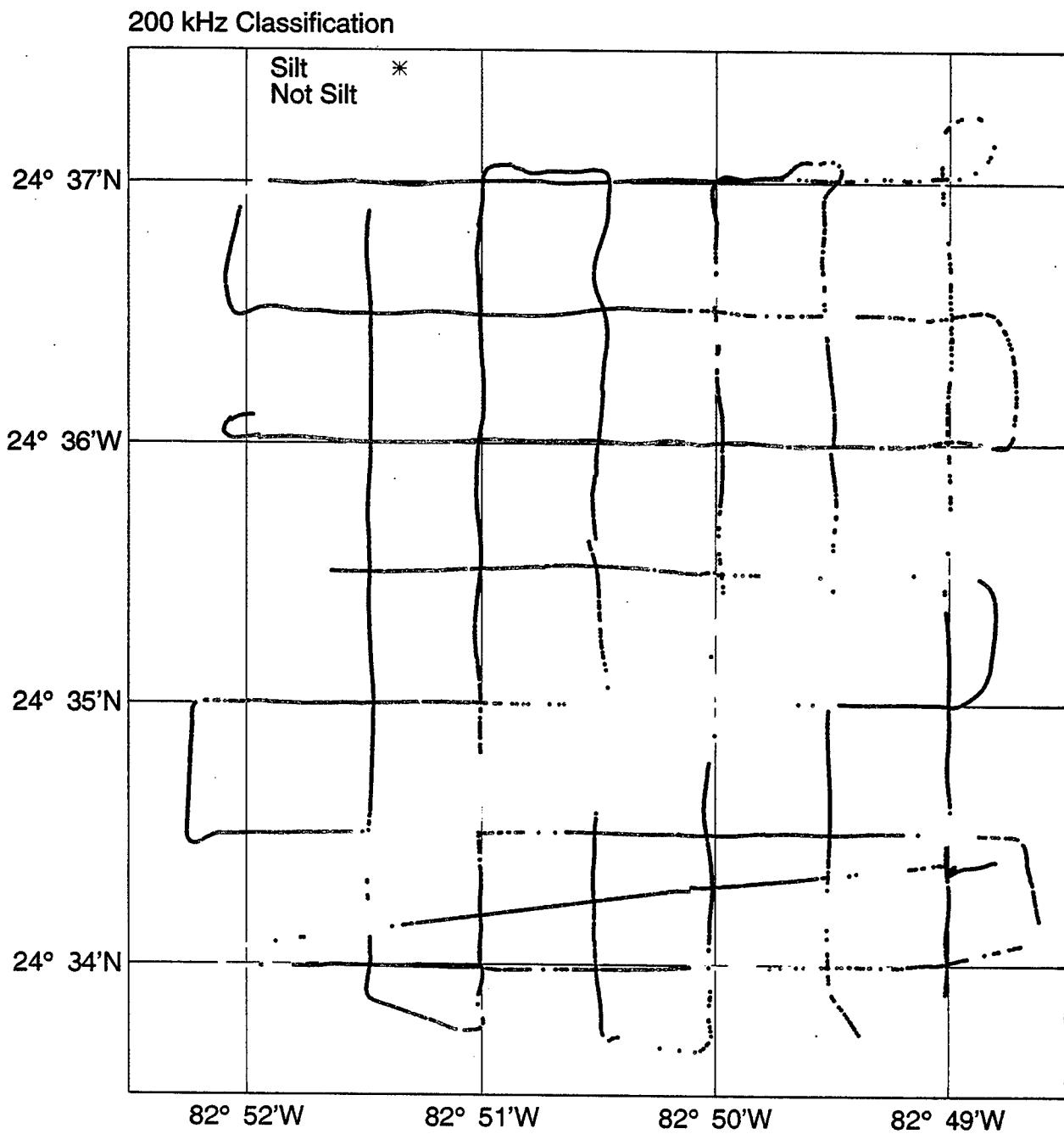


Figure 4.4 Classification of 24 kHz echo sounder data. Classes sand/gravel, reef 1, and reef 2 are all plotted as yellow.

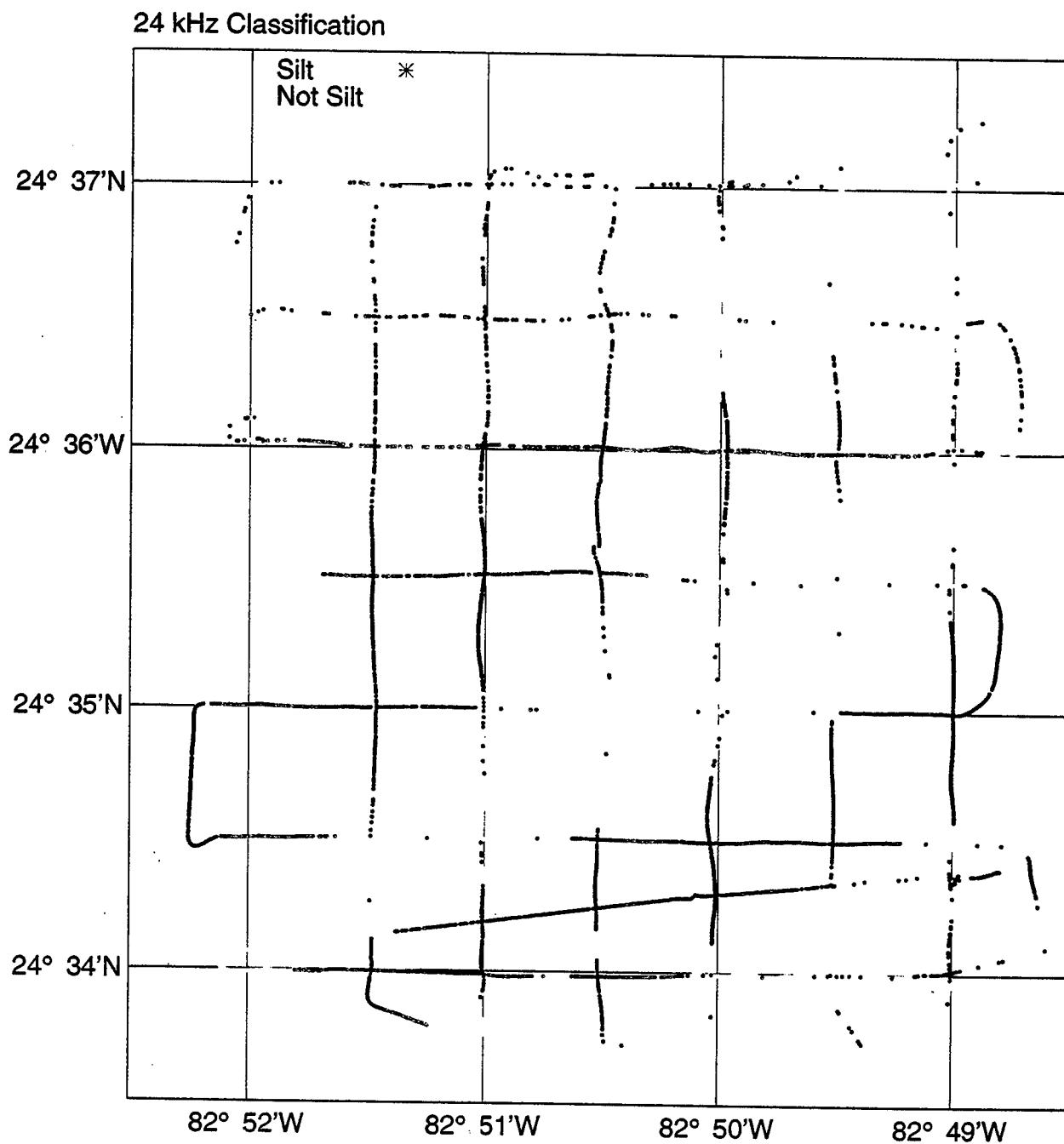


Figure 4.5 200 kHz / 20 traces per proportion.

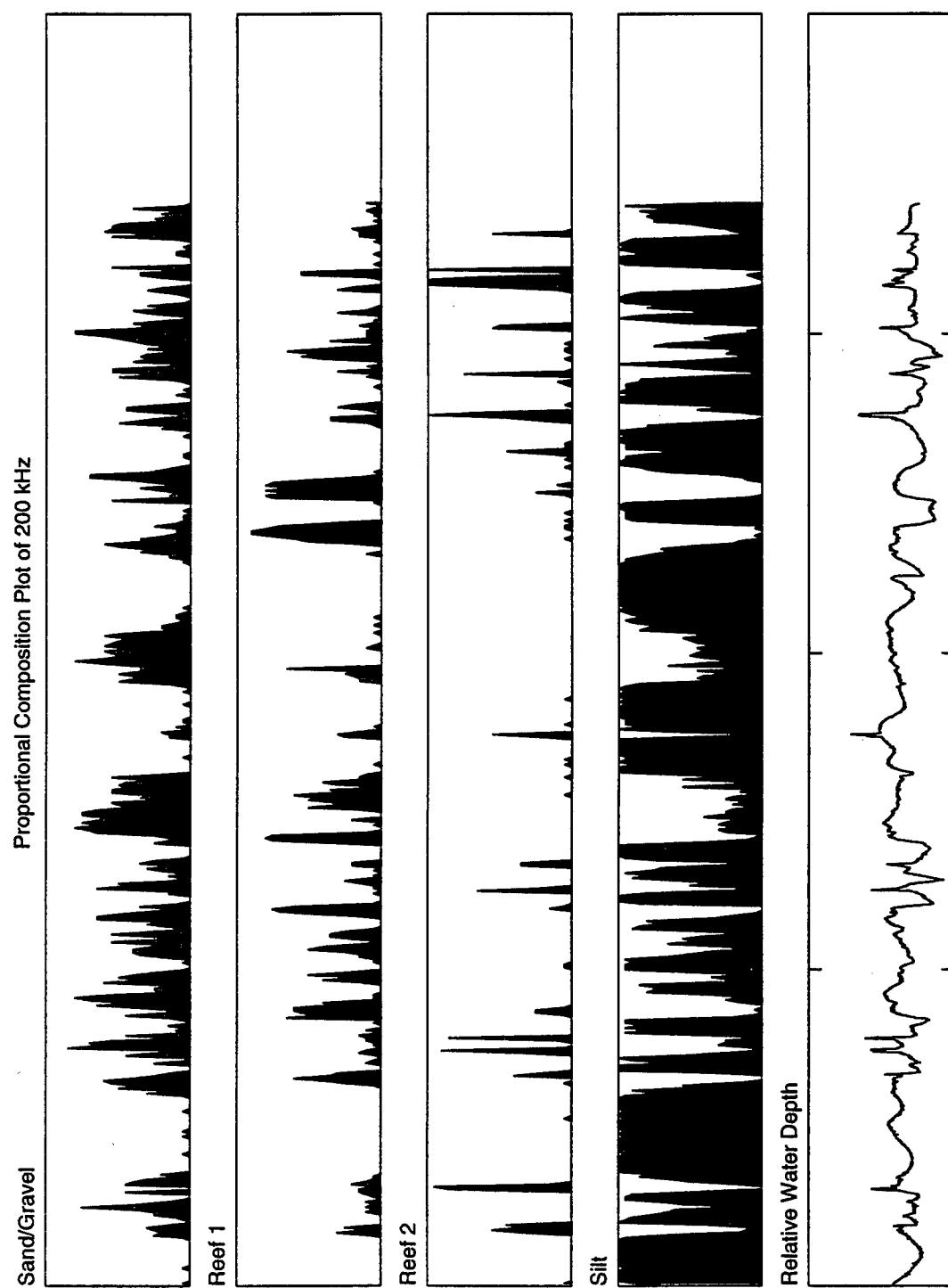
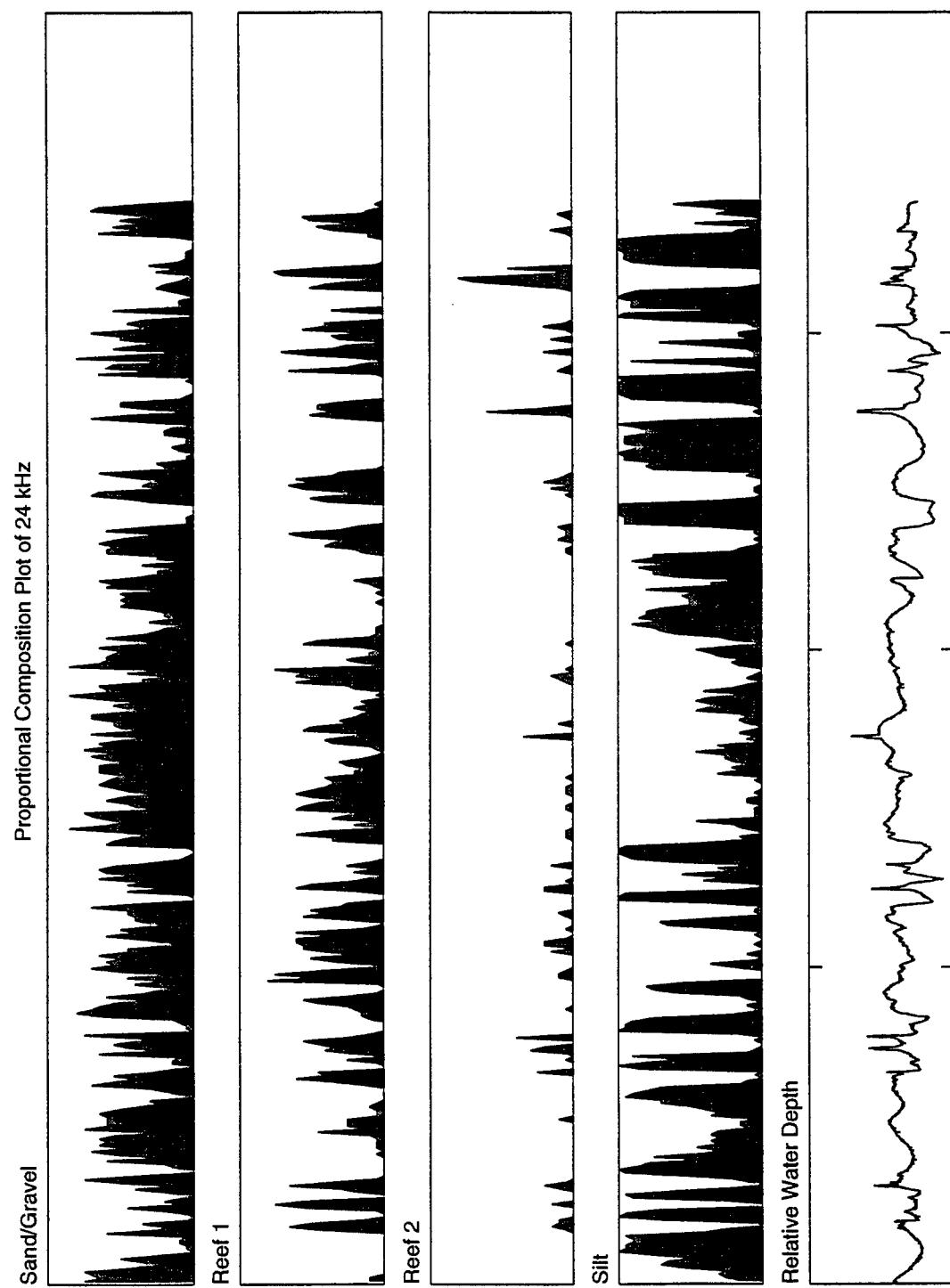


Figure 4.6 24 kHz / 20 traces per proportion.



5. Discussion and Conclusions

5.1 General Results

The cluster analysis produced four different classes in both the 24 kHz and 200 kHz cases. The clusters and results of the unsupervised classification are shown in Figures 3.3 and 3.4. The general orientation of classes is the same for both frequencies although the 200 kHz data exhibit a much greater spread of the 4th class (plotted as cyan) than does the 24 kHz data. Inspection of the locations associated with samples from each cluster class leads to classification into the four categories: silt, sand/gravel, reef 1 and reef 2. The classes and their orientation in reduced feature vector space indicate a coarsening of sediment. Further ground truthing is required to refine these classes and confirm their naming.

Actual classification results are presented in Figures 4.1 and 4.2. Each plotted classification represents the bottom type over about 10m; the size of the colour dots in the figures also represent about 10m. There is very good general agreement between the results from the two frequencies, although the 24 kHz result shows more coarse material. This effect is discussed in Section 5.2 below.

The proportional composition plots (Figures 4.5 and 4.6) show how the seabed grades from one bottom type to another. Figures 4.5 and 4.6 were made by collecting the classification results for all survey lines including turns and plotting them sequentially (basically replaying the survey in proper time sequence).

Proportional composition plots made on a line-by-line basis (waypoint to waypoint) are presented in Appendix B. These plots are most effectively interpreted by comparing the 24 kHz to the 200 kHz plot. In the 200 kHz plot we generally see a greater proportion of silt, and that some areas are exclusively silt. In the 24 kHz plot much of the silt class has moved into the sand/gravel class. The reef 1 class is also larger on the 24 kHz plot; the reef 2 class seems to occur about as frequently as in the 200 kHz case but the proportion is slightly less. These effects are discussed in Section 5.2 below.

5.2 Effect of Echo Sounder Frequency

The effect of the echo sounder frequency is most clearly seen in Figures 4.3 and 4.4. In these both these figures the silt class is plotted in red and all other classes (not silt) plotted in yellow. We see on the 200 kHz plot (Figure 4.3) the only substantial areas of yellow are the three reef flat areas described in Section 2. This result is consistent with the relatively clean reef flat areas shown in the video and interpreted from the general geology of the area. The 24 kHz plot shows

much more yellow (non-silt) areas. The only significant silt areas bracket the central reef flat; the areas over the northern and southern reef flats show much less silt than on the 200 kHz plot. There is no silt area on the 24 kHz plot which is not silt on the 200 kHz plot except for several isolated points.

Interestingly, the 24 kHz plot shows the non-silt class gradually increases towards the northwest. Table 2.2 and Figure 2.1 show the locations for which gravel content with depth cores exist and the increase in gravel content with depth. The cores generally show an increase in gravel content with depth, i.e., the bottom consists of a gravel bottom overlain by silt. It is likely that at 200 kHz there is no penetration and hence the seabed is classified as silt; whereas at 24 kHz the increased penetration into the bottom allows the underlying sediment to be classified.

The proportional composition plots (Figures 4.5 and 4.6) show much the same result. The 24 kHz echo sounder seems to be able to penetrate much of the silt overlying the sand/gravel and reef 1 classes and classify the underlying substrate. The reef 2 class, perhaps associated with newer reef material and associated with the pinnacles does not show an increase in proportion. This indicates that these pinnacles are classified as the same in both the 200 kHz and 24 kHz cases, probably because the pinnacles do not contain pockets of silt as do the reef flats.

Unfortunately the core locations are generally clustered in the northwest quadrant and are not on the lines surveyed with the echo sounders. Additional cores on the survey lines and over the various bottom types shown on the two plots (silt on 200 kHz and 24 kHz; not silt on 200 kHz and 24 kHz; silt on 200 kHz and not silt on 24 kHz) would be quite useful.

5.3 Accuracy

In section 2.5 conclusions regarding the ground truthing interpretation were made. These points are reiterated and examined in light of the acoustic classification:

1. *The bathymetry shows a broad shallowing trend to the northwest. Total relief in the area is approximately 11m. Bathymetric features include a northeast trending trough to the west and a series of pinnacles, 3m and 4m in height, in the southern portion of the survey area.*

The pinnacles are classified as reef 2 on both the 24 kHz and 200 kHz plots (Figures 4.1 and 4.2). The increase in sediment coarseness, especially at 24 kHz is also consistent with the shallowing trend as fine sediments such as

silt tend to be deposited in deeper basins and other areas protected from currents and wave action.

2. *Sediment textural analysis indicates that the majority of sediments can be classed as silts and clayey silts except for samples located at the east central portion of the survey area and along the axis of the northeast trending trough to the west of the survey area.*

Both the 24 kHz and 200 kHz datasets could be divided into only 4 different classes. Based on the above point we have named these classes silt, sand/gravel, reef 1 and reef 2. We suspect reef 1 is old reef and reef 2 is newer reef associated with the several pinnacles found on the old reef flats.

3. *There appears to be an increase in grainsize with subsurface depth, especially in the northwest.*

The increase in the non-silt class towards the northwest for the 24 kHz data relative to the 200 kHz data indicates that as the silt thickness decreases the 24 kHz is able to penetrate the silt and classify the underlying substrate whereas the 200 kHz never penetrates into the substrate and therefore always classifies the overlying silt.

4. *The surficial geology can be classified as two distinct units: reef flat and shallow shelf sediments. While there appears to be some variability in grainsize the patchy nature of the sampling site distribution prohibits a more rigorous classification.*

The reef flat/non reef flat areas have been identified in both the 200 kHz and 24 kHz data.

In total, agreement with known ground truthing interpretation is very good. Individual, detailed comparisons with the actual ground truthing data is impossible as the positioning of the acoustic data is not good enough and most sample sites are not on the lines of the acoustic survey.

5.4 Conclusions

The purpose of this report is to present results of seabed classification processing using the QTC CVIEW system on the Florida Keys data and to compare with known ground truthing. We feel that the classification is good for several reasons:

1. There is very good agreement between the 200 kHz and 24 kHz datasets, especially over the reef 2 areas.
2. Areas of differences between classifications at the two frequencies show an increased sediment coarseness in the 24 kHz results. This is consistent with the greater penetration expected at the lower frequency and the cores which show an increasing sediment coarseness with depth.
3. Generally, the QTC VIEW classification results are consistent with the known geology and ground truthing of the area. We know that there is little variation in seabed type from the ground truthing; this lack of variation (only 4 classes and not much along track variability in the acoustic results) is exhibited by the acoustic data.
4. The 4 classes were generated totally automatically by using a Chi-squared clustering program. Both the 200 kHz and 24 kHz data produced 4 classes; for both frequencies the classes were ordered the same way. These facts indicate that the echo sounders acoustically see the seabed in a similar fashion and give us some confidence that these results can be extended to other areas. Supervised classification with a-priori knowledge can be very effective, especially within the area of the supervised inputs, but can prove to be much more difficult to extend to other areas.

A major area for additional seabed classification processing would be to use a multi-spectral approach to seabed classification. In this approach the 24 kHz and 200 kHz feature vectors are combined and principal component and cluster analysis performed on the combined feature vectors. This should yield a combined seabed/upper sub-bottom classification. We believe that this approach can be extended to the deeper sub-bottom by adding an even lower frequency to the 24 kHz and 200 kHz data. Additional studies measuring the actual penetration into the sub-bottom at the various frequencies would aid the interpretation greatly as the hypothesis that the 24 kHz is classifying the substrate could be confirmed.

The acoustic classification can be interpreted only in a general sense because the ground truthing and acoustic survey positioning is of only a general nature. A more rigorous program combining detailed positioning and ground truthing with an accurate acoustic survey is a necessary next step.

If this experiment were to be repeated or extended, we would make several recommendations:

1. The ground truthing program should be more closely coordinated with the acoustic program. This would allow interpretations and classification success estimates to be made on a more local scale and with greater

confidence. This would also allow supervised classification results to be included with the unsupervised classification results.

2. Surficial grab samples and visual seabed identifications should be made frequently over as wide a variety of bottom types as possible. This would allow the limits of classification resolution to be more properly understood. This would also allow supervised classification to augment the results.
3. A multi-frequency experiment combining several echo sounder frequencies and an experiment to determine depth of penetration at the various frequencies should be performed. This experiment could be used as to investigate the possibility of extending the seabed classification to sub-bottom classification.

6. Appendix A: Ground Truthing Data

Legend to Ground Truthing Data supplied by EDRD:

Core logs from vessel **Planet**: Identified by name Planet in cruise location. Site number used in the Figure 2.2 and Table 3.1 is the numeric part of the station number.

Core logs from vessel **Pelican**: Identified by table title kw-pe-gc-###. Site number used in Figure 2.2 and Table 3.1 is the numeric part of the title.

Cruise: Planet Station: kwp113-2 date: 13 Feb 95													
lat: 24-36.81 N long: 82-50.89 W depth: 26 m													
calc for: 21.0 deg C 36.0 o/oo 26.0 m 400 kHz													
smp core: 6.1 cm thickness													
Depth	Vp	Vp	Alpha	k	Por.	Dens.	e	%	%	%	MGS	Sorting	
(cm)	(m/s)	Ratio	(dB/m)		%	(g/cm ³)		Gravel	Sand	Silt	Clay	(phi)	
1	1522.5	0.998	195.8	0.489	73.87	1.48	2.83	0.00	19.71	43.07	37.21	6.91	3.41
2	1527.1	1.001	212.4	0.531									
3	1532.9	1.005	238.0	0.595	64.54	1.64	1.82	0.03	28.45	38.84	32.68	6.44	3.47
4	1543.9	1.012	295.8	0.739									
5	1549.8	1.016	318.6	0.796	59.81	1.73	1.49	0.05	32.99	35.32	31.63	6.20	3.52
6	1549.8	1.016	321.7	0.804									
7	1547.4	1.015	315.5	0.789	58.75	1.76	1.42	0.08	33.76	36.24	29.92	6.38	3.64
8	1549.4	1.016	324.9	0.812									
9	1554.2	1.019	335.0	0.837	57.37	1.78	1.35	0.48	24.61	41.75	33.16	6.70	3.51
10	1553.0	1.018	335.0	0.837									
11	1553.0	1.018	331.6	0.829	57.42	1.79	1.35	0.06	36.54	34.81	28.58	6.19	3.71
12	1555.4	1.020	349.6	0.874									
13	1553.8	1.019	338.5	0.846	58.12	1.77	1.39	1.00	28.56	37.72	32.72	6.46	3.76
14	1551.0	1.017	335.0	0.837									
15	1549.4	1.016	335.0	0.837	56.45	1.80	1.30	0.07	27.95	41.42	30.56	6.57	3.57
16	1550.6	1.017	335.0	0.837									
17	1551.4	1.017	338.5	0.846	56.92	1.79	1.32	1.91	27.73	40.89	29.48	6.45	3.78
18	1552.6	1.018	353.5	0.884									
19	1551.8	1.017	374.8	0.937	56.67	1.80	1.31	1.01	22.03	41.41	35.54	6.82	3.55
20	1547.0	1.014	357.5	0.894									

Cruise: Planet		Station: kw173-1		date: 18 Feb 95									
calc for: 21.0 deg C 36.0 o/oo		27.0 m 400 kHz											
smp core: 6.1 cm thickness													
Depth	Vp (cm/s)	Vp Ratio	Alpha (dB/m)	k	Por.	Dens. (g/cm ³)	e	% Gr	% Sand	% Silt	% Clay	MGS (phi)	Sorting (phi)
1	1528.0	1.002	188.5	0.471	69.03	1.57	2.23	0.05	31.13	36.86	31.95	6.50	3.74
2	1536.4	1.007	237.1	0.593									
3	1540.3	1.010	264.6	0.662	64.14	1.65	1.79	0.13	30.78	34.45	34.64	6.57	3.87
4	1542.6	1.011	280.7	0.702									
5	1548.1	1.015	306.2	0.766	59.48	1.74	1.47	0.09	35.62	33.12	31.17	6.50	4.06
6	1552.4	1.018	316.8	0.792									
7	1553.2	1.018	306.2	0.766	59.43	1.74	1.46	0.51	33.11	31.84	34.55	6.37	3.80
8	1553.6	1.019	316.8	0.792									
9	1554.4	1.019	340.6	0.851	58.57	1.76	1.41	0.11	28.45	38.36	33.08	6.62	3.76
10	1556.0	1.020	350.6	0.877									
11	1560.0	1.023	350.6	0.877	56.29	1.80	1.29	0.39	41.62	24.31	33.68	6.29	4.37
12	1558.8	1.022	350.6	0.877									
13	1562.8	1.025	369.1	0.923	56.43	1.80	1.30	0.32	32.46	28.22	39.00	6.81	4.01
14	1564.8	1.026	381.5	0.954									
15	1562.8	1.025	377.3	0.943	55.99	1.81	1.27	0.13	48.79	16.29	34.79	6.34	4.42
16	1564.0	1.025	357.7	0.894									
17	1567.2	1.028	365.2	0.913	55.34	1.82	1.24	15.19	24.10	30.22	30.49	4.98	5.24
18	1566.8	1.027	390.4	0.976									
19	1559.2	1.022	369.1	0.923	55.56	1.82	1.25	1.99	35.18	29.93	32.90	6.30	4.27
20	1559.6	1.023	385.9	0.965									

Cruise: Planet		Station: kw192-2		date: 20 Feb 95									
calc for: 21.0 deg C 36.0 o/oo		25.0 m 400 kHz											
smp core: 6.1 cm thickness													
Depth	Vp (cm/s)	Vp Ratio	Alpha (dB/m)	k	Por.	Dens. (g/cm ³)	e	% Gr	% Sand	% Silt	% Clay	MGS (phi)	Sorting (phi)
1	1533.4	1.005	231.9	0.580	70.05	1.55	2.34	0.00	28.47	38.74	32.78	6.73	3.81
2	1539.2	1.009	250.1	0.625									
3	1542.3	1.011	261.0	0.653	63.06	1.67	1.71	0.69	37.24	31.84	30.22	6.16	3.99
4	1541.5	1.011	266.8	0.667									
5	1541.5	1.011	270.8	0.677	61.23	1.71	1.58	0.00	26.05	39.94	34.01	6.71	3.61
6	1546.6	1.014	290.4	0.726									
7	1548.2	1.015	283.6	0.709	59.57	1.74	1.47	0.07	31.86	34.92	33.15	6.58	3.89
8	1549.7	1.016	290.4	0.726									
9	1550.5	1.017	310.5	0.776	58.91	1.76	1.43	0.22	27.51	34.72	37.55	6.90	3.97
10	1547.8	1.015	297.6	0.744									
11	1549.3	1.016	295.2	0.738	59.41	1.75	1.46	0.00	31.15	35.27	33.58	6.53	3.71
12	1549.7	1.016	305.2	0.763									
13	1552.9	1.018	337.0	0.842	58.47	1.76	1.41	0.46	32.51	32.38	34.65	6.60	3.81
14	1556.8	1.021	354.1	0.885									
15	1558.8	1.022	340.2	0.851	57.07	1.79	1.33	1.23	34.88	32.69	31.20	6.50	3.90
16	1563.6	1.025	357.8	0.895									
17	1564.0	1.026	347.0	0.868	55.08	1.82	1.23	0.14	27.88	36.94	35.04	6.75	3.85
18	1562.0	1.024	333.8	0.834									
19	1563.2	1.025	340.2	0.851	54.86	1.83	1.22	0.00	27.66	36.45	35.90	6.70	3.86
20	1561.2	1.024	337.0	0.842									

Cruise: Planet		Station: kw198-1		date: 21 Feb 95													
lat: 24-36.70 N		long: 82-50.71 W		depth: 27 m		Cruise log gives location as 24-36.62 82-50.75											
calc for: 21.0 deg C 36.0 o/oo 27.0 m 400 kHz																	
ref core: 20.0 deg C 32.17 delta-t 469.0 H 0.001 V/D																	
smp core: 36.0 o/oo 6.1 cm thickness																	
Depth	Vp (cm)	Vp (m/s)	Alpha Ratio	k (dB/m)	Por.	Dens. (g/cm ³)	e	% Gr	% Sand	% Silt	% Clay	MGS (phi)	Sorting (phi)				
1	1532.7	1.005	233.5	0.584	70.98	1.53	2.45	0.00	31.00	34.25	34.75	6.75	4.18				
2	1537.3	1.008	250.1	0.625													
3	1539.6	1.010	261.0	0.653	65.15	1.64	1.87	0.05	32.16	37.87	29.91	6.45	3.72				
4	1544.7	1.013	283.6	0.709													
5	1547.8	1.015	285.8	0.715	61.57	1.70	1.60	0.00	32.65	39.60	27.76	6.48	3.73				
6	1549.0	1.016	297.6	0.744													
7	1551.3	1.017	318.8	0.797	60.55	1.72	1.53	0.14	24.22	42.97	32.66	6.74	3.57				
8	1551.3	1.017	321.6	0.804													
9	1551.3	1.017	321.6	0.804	59.95	1.74	1.50	0.10	27.15	42.00	30.75	6.67	3.60				
10	1552.9	1.018	310.5	0.776													
11	1554.5	1.019	327.6	0.819	57.88	1.78	1.37	0.15	28.38	38.88	32.59	6.54	3.56				
12	1552.5	1.018	315.9	0.790													
13	1554.5	1.019	318.8	0.797	58.66	1.76	1.42	0.14	23.10	42.66	34.09	6.79	3.54				
14	1554.1	1.019	340.2	0.851													
15	1554.5	1.019	340.2	0.851	56.84	1.79	1.32	0.03	27.73	36.95	35.29	6.67	3.67				
16	1554.1	1.019	340.2	0.851													
17	1555.7	1.020	357.8	0.895	56.72	1.80	1.31	0.36	35.35	34.18	30.11	6.50	3.86				
18	1557.3	1.021	373.7	0.934													
19	1550.9	1.017	350.5	0.876	56.58	1.80	1.30	0.65	34.63	32.96	31.76	6.28	3.94				
20	1549.8	1.016	347.0	0.868													

Cruise: Planet		Station: kw215-1		date: 22 Feb 95													
lat: 24-36.70 N		long: 82-50.71 W		depth: 27 m													
calc for: 21.0 deg C 36.0 o/oo 27.0 m 400 kHz																	
smp core: 6.1 cm thickness																	
Depth	Vp (cm)	Vp (m/s)	Alpha Ratio	k (dB/m)	Por.	Dens. (g/cm ³)	e	% Gr	% Sand	% Silt	% Clay	MGS (phi)	Sorting (phi)				
1	1544.4	1.013	304.6	0.761	64.49	1.66	1.82	0.12	38.84	32.14	28.90	6.03	3.79				
2	1550.3	1.016	324.7	0.812													
3	1557.0	1.021	351.9	0.880	60.35	1.74	1.52	0.00	44.89	28.12	27.00	5.96	3.97				
4	1559.4	1.022	380.9	0.952													
5	1556.6	1.021	390.4	0.976	57.94	1.78	1.38	0.98	61.06	17.89	20.07	4.92	4.04				
6	1556.6	1.021	385.6	0.964													
7	1554.6	1.019	406.0	1.015	60.86	1.73	1.55	0.00	45.52	27.88	26.60	5.94	3.80				
8	1551.8	1.018	417.4	1.043													
9	1555.0	1.020	400.6	1.002	57.25	1.80	1.34	0.34	45.88	25.90	27.87	5.65	4.10				
10	1559.4	1.022	376.4	0.941													
11	1555.4	1.020	376.4	0.941	55.71	1.82	1.26	0.00	36.44	30.59	32.97	6.14	3.86				
12	1554.2	1.019	376.4	0.941													
13	1554.6	1.019	367.8	0.919	56.83	1.80	1.32	0.33	31.82	30.63	37.22	6.52	3.89				
14	1557.4	1.021	363.7	0.909													
15	1556.6	1.021	367.8	0.919	55.24	1.83	1.23	0.32	27.58	20.14	51.96	7.81	3.76				
16	1560.6	1.023	395.4	0.989													
17	1561.4	1.024	395.4	0.989	53.43	1.86	1.15	0.15	35.69	30.53	33.63	6.25	3.82				
18	1559.0	1.022	367.8	0.919													
19	1557.8	1.021	359.6	0.899	53.93	1.85	1.17	1.05	35.81	19.28	43.86	6.78	3.80				
20	1559.0	1.022	376.4	0.941													

Cruise: Planet				Station: kw223		date: 23 Feb 95																					
lat: 24-36.70 N				long: 82-50.71 W		depth: 27 m																					
calc for: 21.0 deg C 36.0 a/oo 27.0 m 400 kHz																											
smp core: 6.1 cm thickness																											
Depth	Vp (cm)	Vp (m/s)	Alpha Ratio	k (dB/m)	Por. %	Dens. (g/cm3)	e	%	%	%	%	MGS	Sorting														
								Gr	Sand	Silt	Clay	(phi)	(phi)														
1	1523.0	0.999	201.2	0.503	72.46	1.51	2.63	0.00	20.94	34.96	44.10	7.53	3.83														
2	1526.8	1.001	223.4	0.558																							
3	1532.6	1.005	251.4	0.629	66.76	1.61	2.01	0.00	22.04	39.55	38.41	7.04	3.62														
4	1538.0	1.008	275.2	0.688																							
5	1545.0	1.013	309.2	0.773	63.32	1.67	1.73	0.00	30.80	38.01	31.18	6.74	3.87														
6	1550.9	1.017	323.6	0.809																							
7	1551.7	1.017	326.6	0.817	59.66	1.74	1.48	0.00	27.96	37.31	34.73	6.75	3.83														
8	1549.3	1.016	317.6	0.794																							
9	1551.3	1.017	336.2	0.841	59.62	1.74	1.48	0.08	23.98	37.52	38.41	7.07	3.82														
10	1553.3	1.018	343.0	0.858																							
11	1549.3	1.016	326.6	0.817	58.27	1.77	1.40	0.00	27.13	37.92	34.95	6.69	3.66														
12	1546.2	1.014	323.6	0.809																							
13	1548.9	1.016	339.6	0.849	58.76	1.76	1.43	0.11	27.51	42.96	29.42	6.69	3.72														
14	1552.1	1.018	369.7	0.924																							
15	1553.3	1.018	353.8	0.885	59.29	1.75	1.46	1.16	32.18	42.18	24.49	6.37	3.93														
16	1558.1	1.022	343.0	0.858																							
17	1556.5	1.021	361.5	0.904	56.93	1.79	1.32	0.21	26.56	34.98	38.24	6.81	3.87														
18	1554.1	1.019	365.5	0.914																							
19	1548.2	1.015	343.0	0.858	58.90	1.76	1.43	0.00	25.99	36.24	37.77	6.95	3.87														
20	1549.7	1.016	369.7	0.924																							

Cruise: Planet				Station: kw244-1		date: 24 Feb 95																					
lat: 24-36.70 N				long: 82-50.71 W		depth: 27 m																					
calc for: 21.0 deg C 36.0 a/oo 27.0 m 400 kHz																											
smp core: 6.1 cm thickness																											
Depth	Vp (cm)	Vp (m/s)	Alpha Ratio	k (dB/m)	Por. %	Dens. (g/cm3)	e	%	%	%	%	MGS	Sorting														
								Gr	Sand	Silt	Clay	(phi)	(phi)														
1	1528.1	1.002	207.8	0.519	69.75	1.55	2.31	0.00	14.99	40.96	44.05	7.54	3.54														
2	1531.9	1.004	229.5	0.574																							
3	1535.4	1.007	246.1	0.615	65.92	1.62	1.93	0.00	33.43	40.89	25.68	6.21	3.47														
4	1542.4	1.011	291.2	0.728																							
5	1553.4	1.019	329.8	0.824	61.86	1.70	1.62	0.00	28.62	41.20	30.19	6.54	3.80														
6	1552.2	1.018	314.8	0.787																							
7	1551.0	1.017	314.8	0.787	59.89	1.74	1.49	0.00	22.33	37.01	40.66	7.00	3.53														
8	1551.0	1.017	317.6	0.794																							
9	1553.0	1.018	323.6	0.809	59.06	1.75	1.44	0.12	25.77	39.46	34.64	6.73	3.63														
10	1551.8	1.018	323.6	0.809																							
11	1551.8	1.018	323.6	0.809	58.52	1.76	1.41	0.18	23.23	44.48	32.10	6.77	3.60														
12	1550.7	1.017	361.5	0.904																							
13	1547.9	1.015	382.8	0.957	58.22	1.77	1.39	0.34	27.21	39.29	33.16	6.68	3.65														
14	1552.2	1.018	346.5	0.866																							
15	1547.5	1.015	326.6	0.817	59.43	1.75	1.46	0.12	21.30	39.58	38.99	7.07	3.56														
16	1545.1	1.013	317.6	0.794																							
17	1542.8	1.012	303.8	0.759	58.71	1.76	1.42	0.00	23.98	42.35	33.68	6.86	3.58														
18	1550.3	1.016	329.8	0.824																							
19	1560.2	1.023	339.6	0.849	54.69	1.83	1.21	0.01	20.09	40.03	39.87	7.11	3.51														
20	1560.2	1.023	339.6	0.849																							

Cruise: Planet			Station: kw244-2		date: 24 Feb 95													
lat: 24-36.70 N			long: 82-50.71 W		depth: 27 m													
calc for: 21.0 deg C 36.0 o/oo 27.0 m 400 kHz																		
smp core: 6.1 cm thickness																		
Depth	Vp	Vp	Alpha	k	Por.	Dens.	e	%	%	%	%	MGS	Sorting					
(cm)	(m/s)	Ratio	(dB/m)		%	(g/cm ³)		Gr	Sand	Silt	Clay	(phi)	(phi)					
1	1522.7	0.998	205.1	0.513	72.92	1.50	2.69	0.00	22.85	35.24	41.91	7.31	3.81					
2	1528.1	1.002	232.6	0.582														
3	1532.3	1.005	246.1	0.615	66.05	1.62	1.95	0.00	22.60	37.54	39.85	7.10	3.66					
4	1538.1	1.009	268.9	0.672														
5	1543.2	1.012	291.2	0.728	62.46	1.69	1.66	0.00	22.63	42.29	35.08	6.84	3.54					
6	1546.7	1.014	309.2	0.773														
7	1548.3	1.015	314.8	0.787	60.40	1.73	1.53	0.05	25.42	38.92	35.62	6.73	3.68					
8	1550.3	1.016	326.6	0.817														
9	1547.5	1.015	309.2	0.773	59.03	1.75	1.44	0.08	30.74	37.69	31.49	6.73	3.98					
10	1551.0	1.017	317.6	0.794														
11	1553.8	1.019	323.6	0.809	57.53	1.78	1.35	0.12	23.24	40.43	36.21	6.90	3.62					
12	1552.6	1.018	323.6	0.809														
13	1551.4	1.017	333.0	0.832	59.64	1.74	1.48	0.24	28.27	34.57	36.92	6.73	3.78					
14	1551.8	1.018	361.5	0.904														
15	1553.0	1.018	353.8	0.885	57.81	1.78	1.37	0.32	28.43	33.62	37.63	6.80	3.90					
16	1553.0	1.018	357.6	0.894														
17	1551.8	1.018	365.5	0.914	56.98	1.79	1.32	0.33	29.19	37.31	33.18	6.46	3.65					
18	1553.4	1.019	365.5	0.914														
19	1552.2	1.018	382.8	0.957	57.70	1.78	1.36	0.21	27.17	34.71	37.91	6.87	3.82					
20	1547.9	1.015	378.3	0.946														

Cruise: Planet			Station: kw263		date: 25 Feb 95													
lat: 24-35.97 N			long: 82-49.00 W		depth: 24 m													
calc for: 21.0 deg C 36.0 o/oo 24.0 m 400 kHz																		
smp core: 6.1 cm thickness																		
Depth	Vp	Vp	Alpha	k	Por.	Dens.	e	%	%	%	%	MGS	Sorting					
(cm)	(m/s)	Ratio	(dB/m)		%	(g/cm ³)		Gr	Sand	Silt	Clay	(phi)	(phi)					
1	1651.0	1.083	287.9	0.720	45.81	1.99	0.85	0.90	91.11	5.26	2.73	1.00	1.33					
2	1659.1	1.088	314.8	0.787														
3	1668.2	1.094	306.2	0.765	44.89	2.00	0.81	0.90	94.03	1.72	3.35	1.05	0.98					
4	1674.6	1.098	261.1	0.653														
5	1679.3	1.101	265.2	0.663	44.65	2.01	0.81	0.66	93.90	3.39	2.05	1.10	1.06					
6	1680.2	1.102	271.7	0.679														
7	1679.3	1.101	263.2	0.658	45.55	2.00	0.84	0.80	91.18	3.90	4.13	1.35	1.51					
8	1677.4	1.100	283.1	0.708														
9	1675.6	1.099	303.4	0.759	44.67	2.01	0.81	1.07	91.55	3.29	4.09	1.15	1.49					
10	1674.6	1.098	344.4	0.861														
11	1669.1	1.094	413.5	1.034	46.47	1.99	0.87	2.10	89.89	3.48	4.54	1.08	1.62					
12	1669.1	1.094	512.2	1.281														

kw-pe-gc-167

Sample	Wet Bulk	Grain	Water	Void	Por.	%	%	%	%	MGS	p-wave
Interval	Density	Density	Content	Ratio		Grav.	Sand	Silt	Clay	(phi)	velocity
	(g/cc)	(g/cc)	(%)		(%)						(m/s)
0-2	1.56	2.70	67.13	1.81	64.44	0.5	29.9	52.6	17.0	5.70	1629.47
2-4	1.70	2.72	53.31	1.45	59.17						1633.81
4-6	1.73	2.71	56.59	1.53	60.52						1641.74
6-8	1.73	2.71	52.62	1.43	58.81						1640.35
8-10	1.76	2.71	49.11	1.33	57.11						1641.94
10-12	1.75	2.72	46.92	1.28	56.06	3.2	40.2	43.1	13.6	4.53	1648.35
12-14	1.86	2.71	46.30	1.26	55.69						1637.17
14-16	1.83	2.72	43.08	1.17	53.93						1643.54
16-18	1.80	2.72	49.83	1.35	57.50						1648.35
18-20	1.82	2.72	41.71	1.13	53.16						1648.54
20-22	1.85	2.72	42.26	1.15	53.49	2.3	41.0	42.2	14.5	5.05	1648.54
Latitude 24 d N	35.952'										
Longitude 82 d W	51.517'										

kw-pe-gc-147

Sample	Wet Bulk	Grain	Water	Void	Por.	%	%	%	%	MGS	%	p-wave
Interval	Density	Density	Content	Ratio		Grav.	Sand	Silt	Clay	(phi)	Carb	velocity
	(g/cc)	(g/cc)	(%)		(%)							(m/s)
0-2	1.68	2.72	58.18	1.58	61.26	0.0	21.6	61.1	17.4	6.08	92.1	1595.65
2-4	1.68	2.70	57.99	1.57	61.04						91.8	1595.85
4-6	1.75	2.73	51.07	1.39	58.20						91.7	1595.85
6-8	1.70	2.73	55.05	1.50	60.08						90.4	1600.50
8-10	1.76	2.73	47.76	1.30	56.60						91.8	1597.59
10-12	1.76	2.75	47.92	1.32	56.86	0.1	26.4	57.9	15.7	5.75	88.4	1603.81
12-14	1.80	2.73	44.15	1.21	54.69						91.1	1603.81
14-16	1.78	2.74	45.41	1.24	55.41						88.8	1602.44
16-18	1.78	2.72	46.44	1.26	55.81						91.6	1599.33
18-20	1.79	2.74	46.16	1.26	55.83						88.7	1602.44
20-22	1.82	2.72	42.81	1.16	53.79	1.0	32.7	49.6	16.8	5.65	90.1	1600.89
Latitude 24 d N	36.562'											
Longitude 82 d W	51.566'											

kw-pe-gc-178

Sample	Wet Bulk	Grain	Water	Void	Por.	%	%	%	%	MGS	p-wave
Interval	Density	Density	Content	Ratio		Grav.	Sand	Silt	Clay	(phi)	velocity
	(g/cc)	(g/cc)	(%)		(%)						(m/s)
0-2	1.74	2.71	44.30	1.17	53.93	2.23	39.71	46.97	11.09	4.42	90.6
2-4	1.78	2.76	42.47	1.14	53.36						
4-6	1.72	2.71	47.27	1.25	55.56						
6-8	1.73	2.72	45.43	1.21	54.66						
8-10	1.73	2.75	46.86	1.26	55.68						
10-12	1.75	2.74	45.04	1.21	54.66	0.67	29.21	53.42	16.71	5.63	91.3
12-14	1.73	2.74	46.60	1.25	55.48						
14-16	1.75	2.71	43.72	1.16	53.66						
16-18	1.77	2.74	42.99	1.15	53.52						
18-20	1.73	2.74	46.75	1.25	55.56						
20-22	1.80	2.73	38.88	1.04	50.87	0.68	31.61	51.32	16.39	5.60	91.6
Latitude 24 d N	36.49'										
Longitude 82 d W	51.32'										

kw-pe-gc-203

Sample Interval	Wet Bulk Density	Grain Density	Water Content	Void Ratio	Por.	% Grav.	% Sand	% Silt	% Clay	MGS (phi)	% Carb	p-wave velocity (m/s)
	(g/cc)	(g/cc)	(%)		(%)							
0-2	1.75	2.66	42.33	1.10	52.37	4.39	18.2	61.7	15.77	5.82	81.0	1625.55
2-4	1.78	2.72	40.39	1.07	51.75							88.1
4-6	1.79	2.70	39.12	1.03	50.74							84.5
6-8	1.82	2.71	36.73	0.97	49.27							86.4
8-10	1.80	2.68	37.36	0.98	49.42							86.2
10-12	1.86	2.75	34.74	0.93	48.26	25.3	12.3	49.3	13.1	3.55	84.4	1637.36
12-14	1.89	2.74	31.93	0.85	46.05							87.2
14-16	1.96	2.72	27.02	0.72	41.83							85.3
16-18	1.89	2.71	31.33	0.83	45.34							85.8
18-20	1.85	2.71	34.44	0.91	47.67							88.3
20-22	1.83	2.71	35.73	0.95	48.59	13.8	15.71	54	16.5	4.63	83.1	1635.89
Latitude 24 d N	45.08°											
Longitude 82 d W	11.96°											

kw-pe-gc-208

Sample Interval	Wet Bulk Density	Grain Density	Water Content	Void Ratio	Por.	% Gravel	% Sand	% Silt	% Clay	% Carb
0-2	1.79	2.73	40.81	1.09	52.15					87.8
2-4	1.79	2.73	40.76	1.09	52.12					
4-6	1.77	2.73	42.25	1.13	53.01					
6-8	1.78	2.73	41.76	1.11	52.71					
8-10	1.78	2.74	41.06	1.10	52.33					
10-12	1.79	2.74	40.62	1.09	52.09					88.3
12-14	1.75	2.73	43.72	1.17	53.82					
14-16	1.77	2.73	41.78	1.11	52.69					
16-18	1.78	2.73	41.51	1.11	52.56					
18-20	1.78	2.73	41.20	1.10	52.33					
Latitude 24 d N	36.67°									
Longitude 82 d W	51.99°									

kw-pe-gc-210

Sample Interval	Wet Bulk Density	Grain Density	Water Content	Void Ratio	Por.	% Gravel	% Sand	% Silt	% Clay	MGS (phi)	% Carb	p-wave velocity (m/s)
	(g/cc)	(g/cc)	(%)		(%)							
0-2	1.69	2.71	50.24	1.33	57.08	0.58	22.67	56.2	20.54	6.03	84.8	
2-4	1.68	2.73	52.76	1.41	58.48							
4-6	1.71	2.73	49.27	1.32	56.81							
6-8	1.74	2.72	44.95	1.20	54.46							
8-10	1.72	2.76	47.98	1.29	56.37							
10-12	1.75	2.73	44.76	1.19	54.43	1.79	21	59	18.2	5.6	87.1	
12-14	1.74	2.74	45.86	1.23	55.10							
14-16	1.67	2.73	53.27	1.42	58.70							1632.98
16-18	1.67	2.74	53.64	1.44	58.94							1611.34
18-20	1.70	2.74	50.62	1.36	57.55							1572.03
20-22	1.70	2.75	50.61	1.36	57.61	1.55	25.5	47.2	25.79	4.97	86.9	1586.73
Latitude 24 d N	36.48°											
Longitude 82 d W	51.77°											

kw-pe-gc-213

Sample Interval	Wet Bulk Density (g/cc)	Grain Density (g/cc)	Water Content (%)	Void Ratio	Por. (%)	% Gravel	% Sand	% Silt	% Clay	MGS (phi)	% Carb	p-wave velocity (m/s)
0-2	1.68	2.74	52.74	1.41	58.49	0.02	13.25	68.56	18.15	6.42	88.4	
2-4	1.65	2.74	56.16	1.50	60.04							
4-6	1.66	2.74	55.64	1.49	59.85							
6-8	1.68	2.74	53.19	1.42	58.75							
8-10	1.73	2.74	46.65	1.25	55.51							
10-12	1.78	2.74	41.25	1.10	52.45	0.1	14.09	65.93	19.87	6.35	88.7	
12-14	1.80	2.74	39.22	1.05	51.21							
14-16	1.80	2.74	39.39	1.05	51.27							
16-18	1.78	2.74	41.21	1.10	52.42							
18-20	1.80	2.73	38.99	1.04	51.00							
20-22	1.79	2.74	40.59	1.08	52.03	0.32	15.31	63.48	20.89	6.65	89.1	
Latitude 24 d N	36.42'											
Longitude 82 d W	51.98'											

kw-pe-gc-218

Sample Interval	Wet Bulk Density (g/cc)	Grain Density (g/cc)	Water Content (%)	Void Ratio	Por. (%)	% Gravel	% Sand	% Silt	% Clay	MGS (phi)	p-wave velocity (m/s)
0-2	1.54	2.74	75.20		66.76	0.04	23.61	56.36	19.99	6.15	
2-4	1.74	2.75	45.56	1.22	55.00						
4-6	1.78	2.74	41.49	1.11	52.62						
6-8	1.78	2.74	41.27	1.11	52.51						
8-10	1.75	2.75	44.48	1.19	54.40						
10-12	1.86	2.75	35.04	0.94	48.45	0.53	31	49.25	19.22	5.82	
12-14	1.82	2.74	37.53	1.00	50.12						
14-16	1.84	2.74	36.54	0.98	49.45						1586.9
16-18	1.85	2.74	35.30	0.94	48.57						1600.9
18-20	1.85	2.73	34.81	0.93	48.16						1605.7
20-22	1.84	2.74	36.15	0.97	49.17	1.35	37.05	44.43	17.18	5.52	1604.1
Latitude 24 d N	36.273'										
Longitude 82 d W	51.727'										

kw-pe-gc-220

Sample Interval	Wet Bulk Density (g/cc)	Grain Density (g/cc)	Water Content (%)	Void Ratio	Porosity (%)	p-wave velocity (m/s)
0-2	1.55	2.66		70.03	1.82	64.48
2-4	1.58	2.68		65.00	1.70	63.00
4-6	1.61	2.70		60.34	1.59	61.37
6-8	1.69	2.69		49.61	1.30	56.56
8-10	1.73	2.70		45.31	1.19	54.42
10-12	1.73	2.69		44.89	1.18	54.14
12-14	1.76	2.71		42.26	1.12	52.78
14-16	1.77	2.68		41.01	1.08	51.81
16-18	1.77	2.70		40.97	1.08	51.95
18-20	1.78	2.72		40.95	1.09	52.10
20-22	1.75	2.72		43.88	1.16	53.80
Latitude 24 d N	36.513'					
Longitude 82 d W	51.714'					

kw-pe-gc-222

Sample Interval	Wet Bulk Density	Grain Density	Water Content	Void Ratio	Por.	% Gravel	% Sand	% Silt	% Clay	MGS (phi)	% Carb	p-wave velocity
	(g/cc)	(g/cc)	(%)		(%)							(m/s)
0-2	1.71	2.70	47.16	1.24	55.39	0	12.31	70.71	17.03	6.27	90.6	
2-4	1.71	2.70	48.09	1.27	55.88							
4-6	1.76	2.73	42.95	1.15	53.42							
6-8	1.74	2.69	44.37	1.17	53.83							
8-10	1.75	2.73	44.33	1.18	54.19							
10-12	1.77	2.73	42.10	1.12	52.90	0.166	14.69	67.3	17.83	6.3	91.8	
12-14	1.76	2.71	42.98	1.14	53.23							
14-16	1.78	2.71	40.70	1.08	51.82							
16-18	1.82	2.70	36.21	0.96	48.86							
18-20	1.81	2.69	36.92	0.97	49.28							1608.80
20-22	1.83	2.72	35.97	0.96	48.86	0.68	16.02	63.8	19.48	6.42	93.1	
Latitude 24 d N	36.775'											
Longitude 82 d W	51.756'											

kw-pe-gc-224

Sample Interval	Wet Bulk Density	Grain Density	Water Content	Void Ratio	Por.	% Gravel	% Sand	% Silt	% Clay	MGS (phi)	% Carb	p-wave velocity
	(g/cc)	(g/cc)	(%)		(%)							(m/s)
0-2	1.71	2.73	48.29	1.29	56.32	0.18	27.37	56	16.42	5.72	92.8	
2-4	1.75	2.76	45.52	1.23	55.10							
4-6	1.71	2.80	50.19	1.37	57.81							
6-8	1.71	2.75	48.88	1.31	56.80							
8-10	1.74	2.75	45.83	1.23	55.20							
10-12	1.73	2.73	46.23	1.23	55.23	0.5	21.1	58.4	19.99	6.06	94.0	
12-14	1.75	2.76	45.46	1.22	55.05							
14-16	1.74	2.72	45.28	1.20	54.62							
16-18	1.75	2.75	44.44	1.19	54.39							
18-20	1.78	2.75	42.19	1.13	53.09							
20-22	1.78	2.74	41.74	1.12	52.80	0.81	32.31	50.2	16.72	5.56	92.4	
Latitude 24 d N	36.769'											
Longitude 82 d W	51.282'											

kw-pe-gc-225

Sample Interval	Wet Bulk Density	Grain Density	Water Content	Void Ratio	Por.	% Gravel	% Sand	% Silt	% Clay	MGS (phi)	p-wave velocity
	(g/cc)	(g/cc)	(%)		(%)						(m/s)
0-2	1.81	2.71	37.70	1.00	49.94	0.04	31.01	50.89	18.06	5.92	1583.15
2-4	1.78	2.72	40.55	1.08	51.84						1580.07
4-6	1.82	2.73	37.70	1.00	50.12						1580.65
6-8	1.82	2.71	37.16	0.98	49.61						1576.63
8-10	1.87	2.73	33.66	0.90	47.30						1584.91
10-12	1.85	2.71	34.62	0.92	47.79	1.79	26.62	52.73	18.86	6.32	1583.56
12-14	1.85	2.73	35.25	0.94	48.44						1583.76
14-16	1.85	2.79	36.90	1.01	50.13						1577.61
16-18	1.87	2.72	32.61	0.86	46.38						1580.68
18-20	1.84	2.71	35.49	0.94	48.42						1574.74
20-22	1.87	2.71	32.88	0.87	46.54	0.59	30.32	48.55	20.54	6.02	1580.87
Latitude 24 d N	36.706'										
Longitude 82 d W	51.338'										

kw-pe-gc-227

Sample Interval	Wet Bulk Density (g/cc)	Grain Density (g/cc)	Water Content (%)	Void Ratio	Por.	% Gravel	% Sand	% Silt	% Clay	MGS (phi)	p-wave velocity (m/s)
0-2	1.69	2.73	51.12	1.37	57.84	0.39	28.98	55.74	14.87	5.64	
2-4	1.74	2.75	45.94	1.23	55.18						
4-6	1.73	2.74	47.03	1.26	55.78						
6-8	1.74	2.75	46.12	1.24	55.34						
8-10	1.74	2.75	45.80	1.23	55.19						
10-12	1.73	2.75	47.09	1.26	55.78	0.39	25.55	55.88	18.17	5.93	
12-14	1.74	2.74	45.55	1.22	54.99						
14-16	1.69	2.75	51.48	1.39	58.08						
16-18	1.74	2.76	45.55	1.22	55.03						
18-20	1.77	2.75	42.89	1.15	53.52						
20-22	1.80	2.75	40.24	1.08	51.97	1.29	33.49	47.45	17.76	5.72	
Latitude 24 d N	36.297'										
Longitude 82 d W	51.322'										

kw-pe-gc-285

Sample Depth	Wet Bulk Density
0	1.91
2	1.90
4	2.02
6	2.06
8	1.97
10	1.94
12	2.01
14	1.99
16	1.95
18	1.98
Latitude 24 d N	42.515'
Longitude 82 d W	11.941'

kw-pe-gc-179

Sample Depth	Wet Bulk Density
0	1.65
2	1.72
4	1.74
6	1.76
8	1.77
10	1.76
12	1.76
14	1.76
16	1.77
18	1.79
Latitude 24 d N	35.999'
Longitude 82 d W	51.283'

7. Appendix B: Proportional Composition Plots

Figure B.1 Waypoint locations.

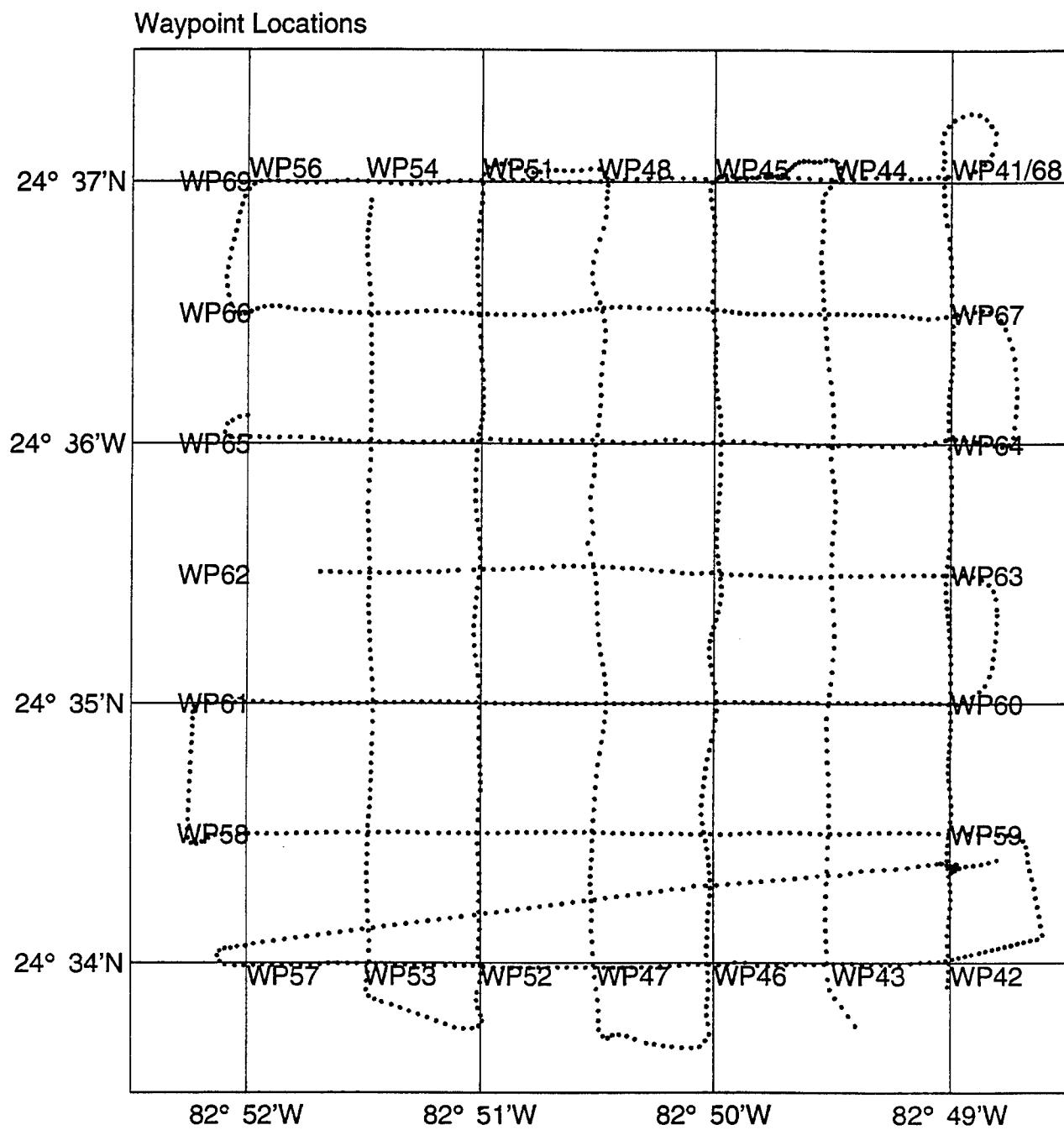


Figure B.2 WP 54 - WP 53.

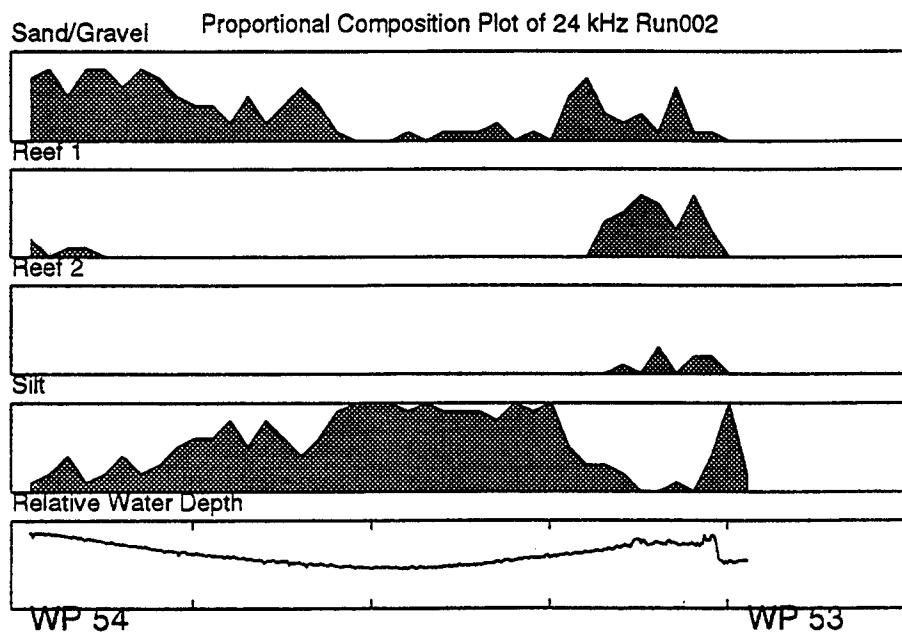
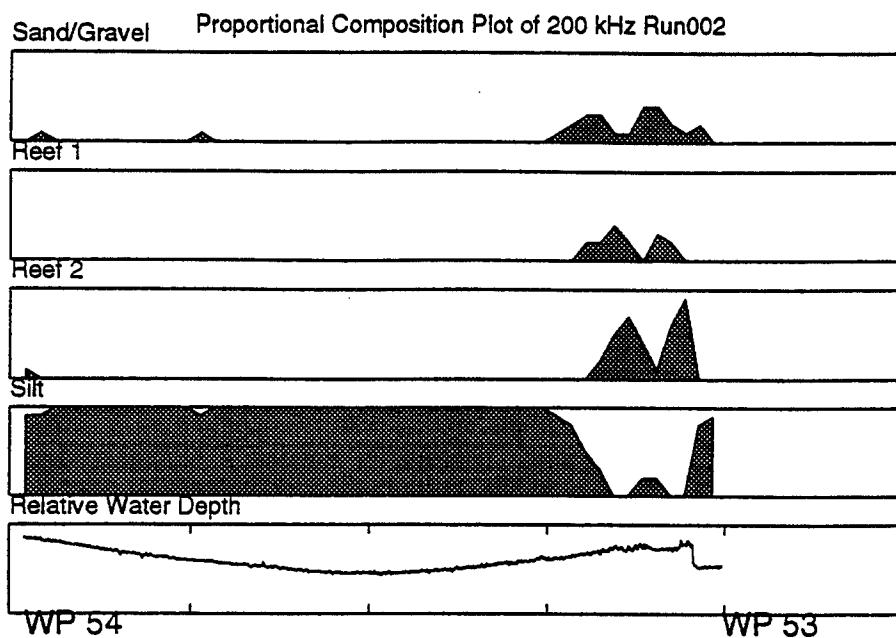


Figure B.3 WP 52 - WP 51.

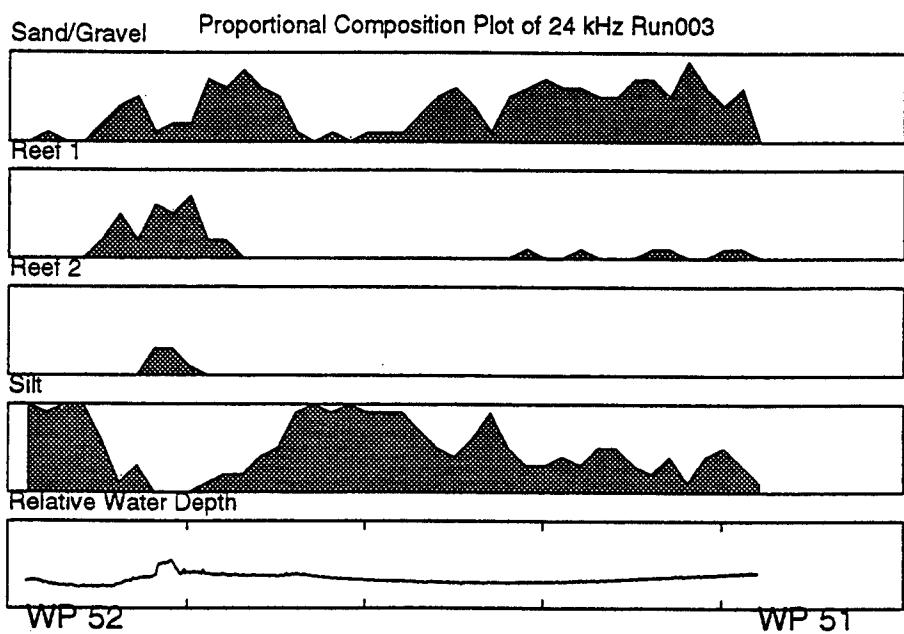
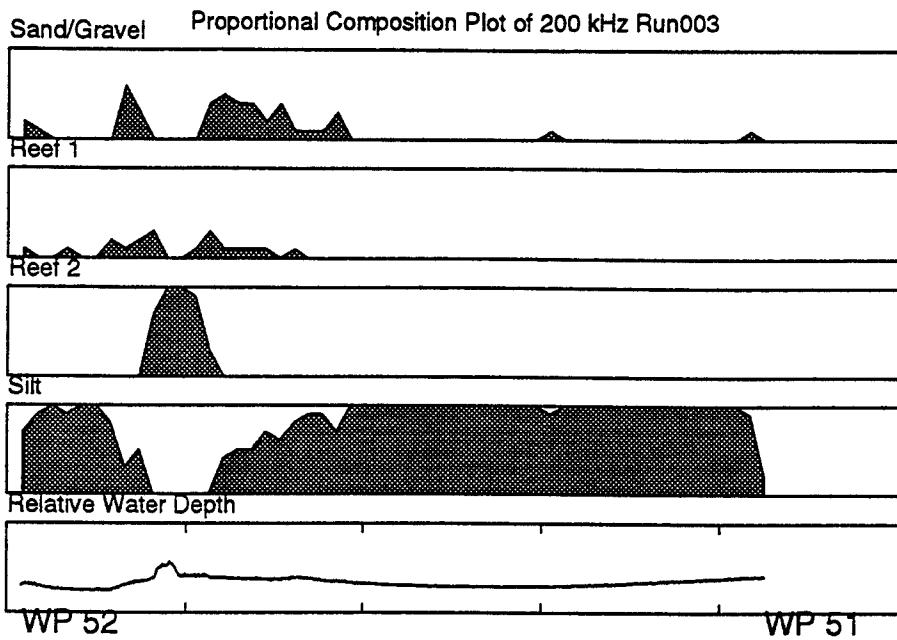


Figure B.4 WP 48 - WP 47.

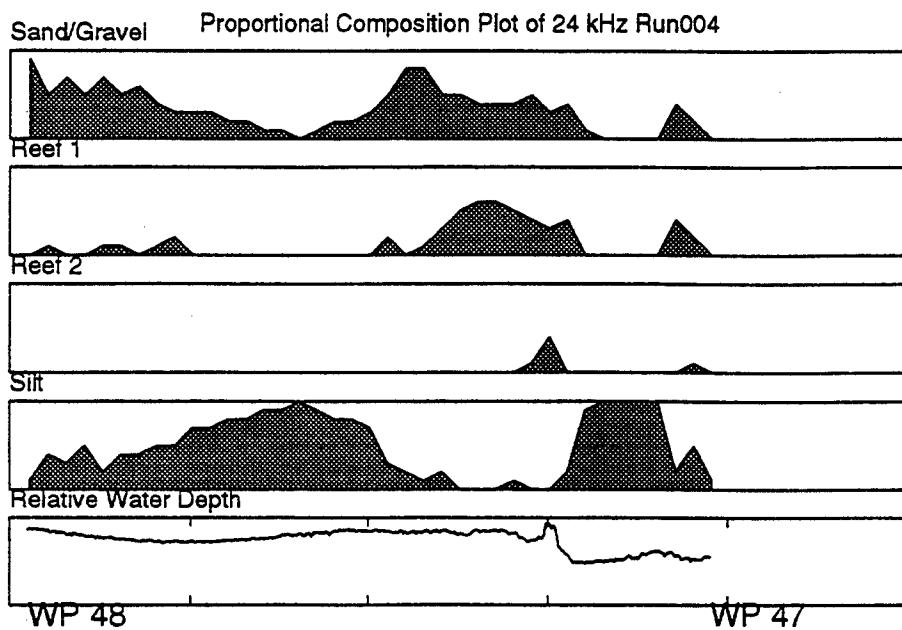
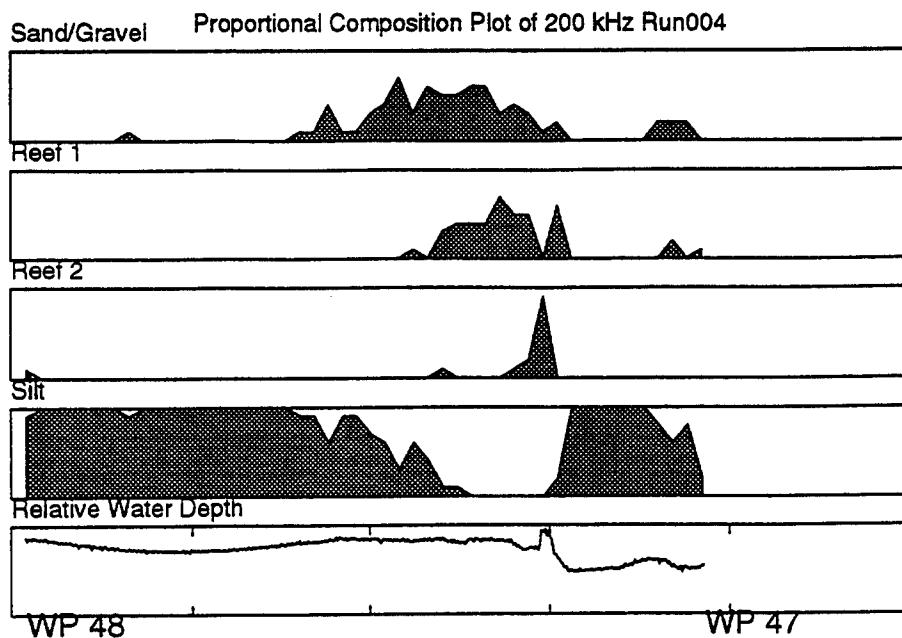


Figure B.5 WP 46 - WP 45.

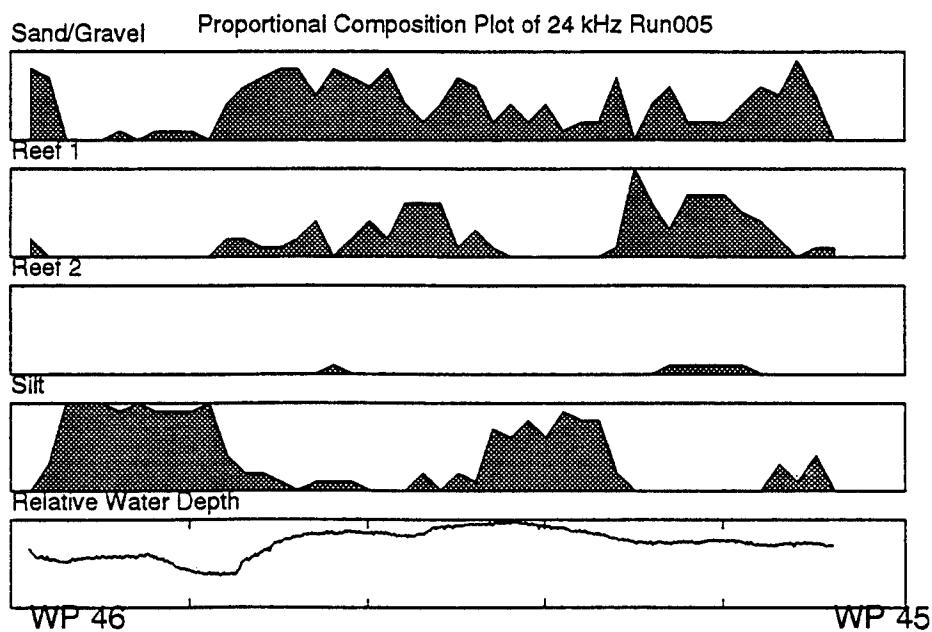
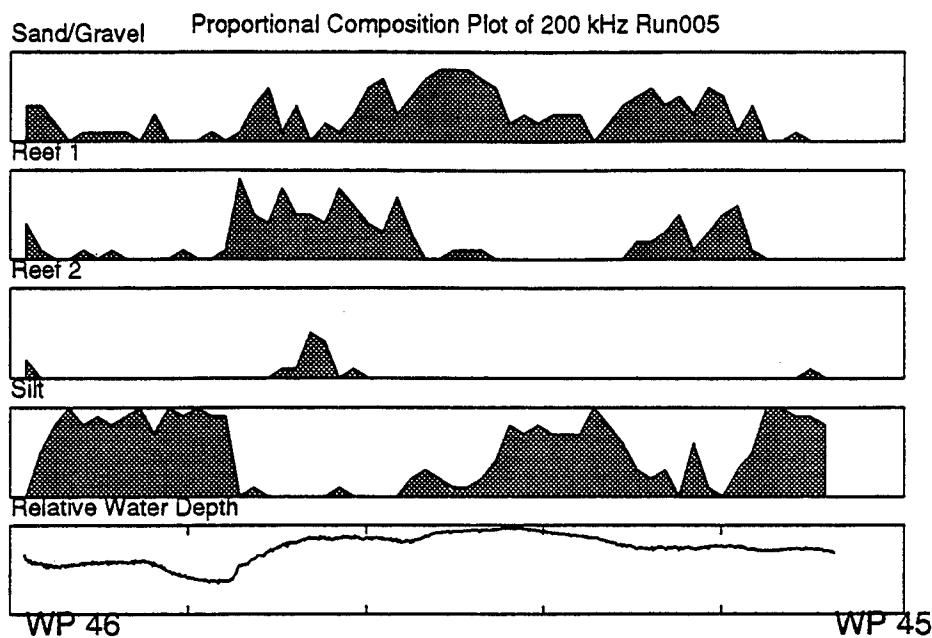


Figure B.6 WP 44 - WP 43.

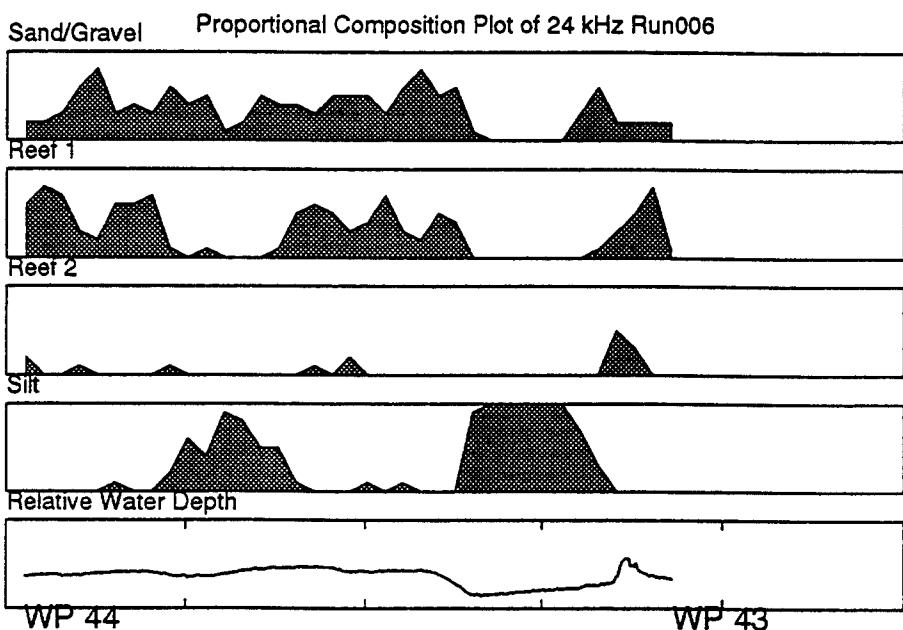
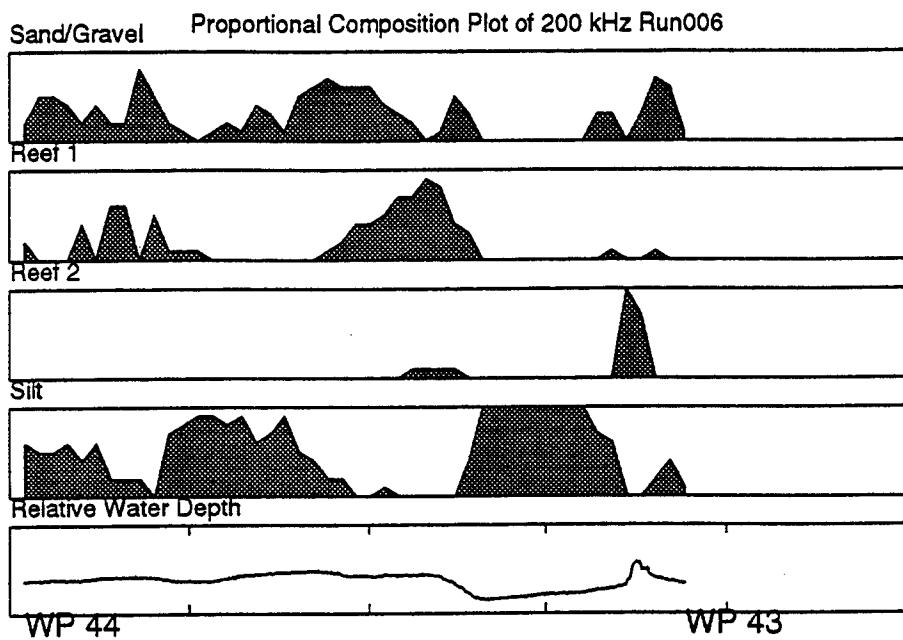


Figure B.7 WP 42 - WP 41.

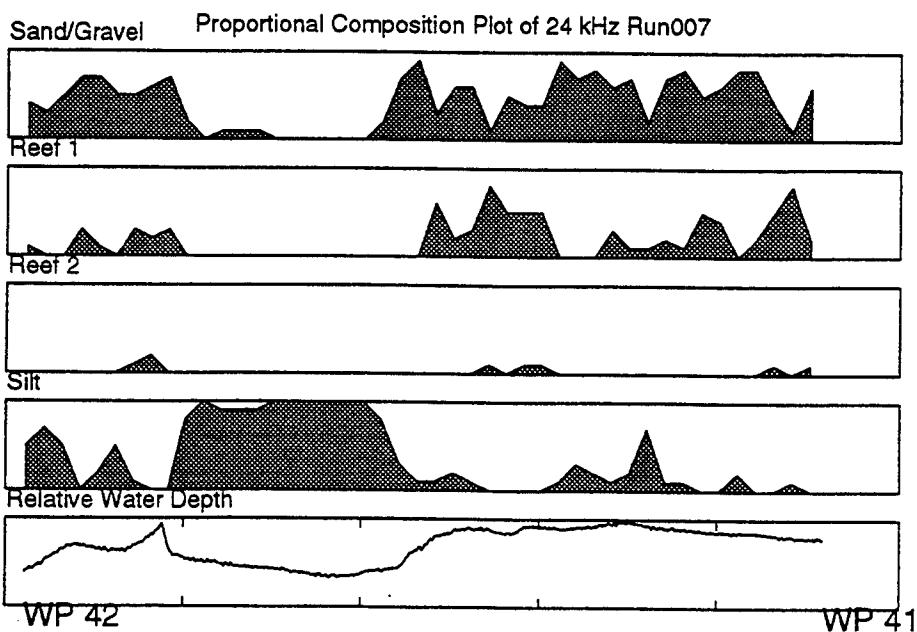
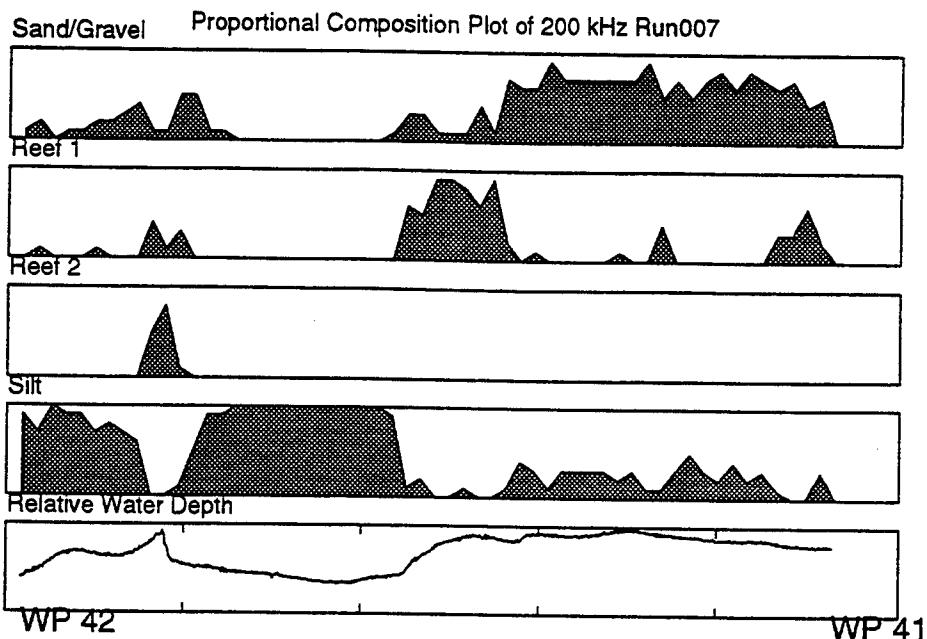


Figure B.8 WP 68 - WP 69.

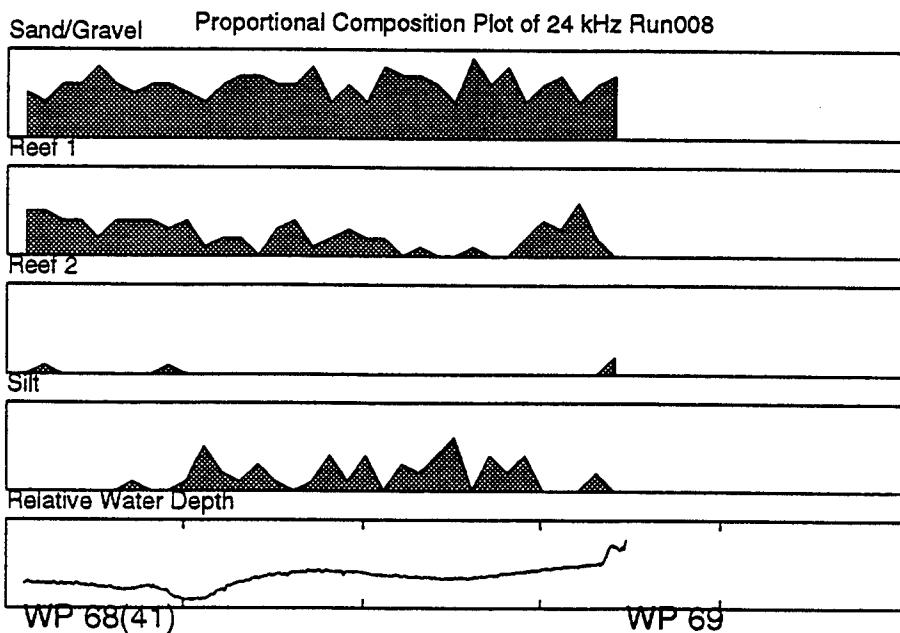
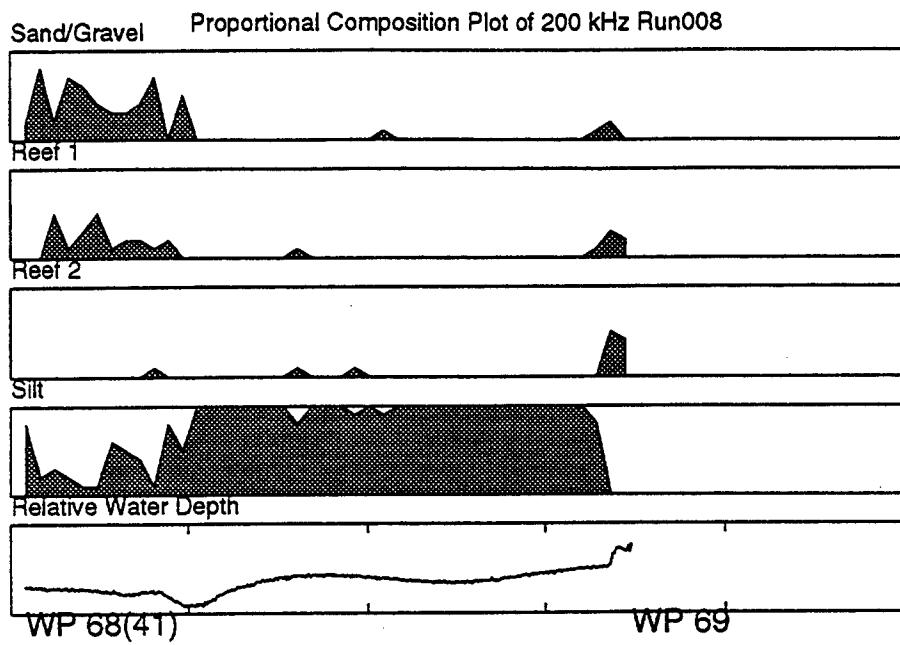


Figure B.9 WP 66 - WP 67.

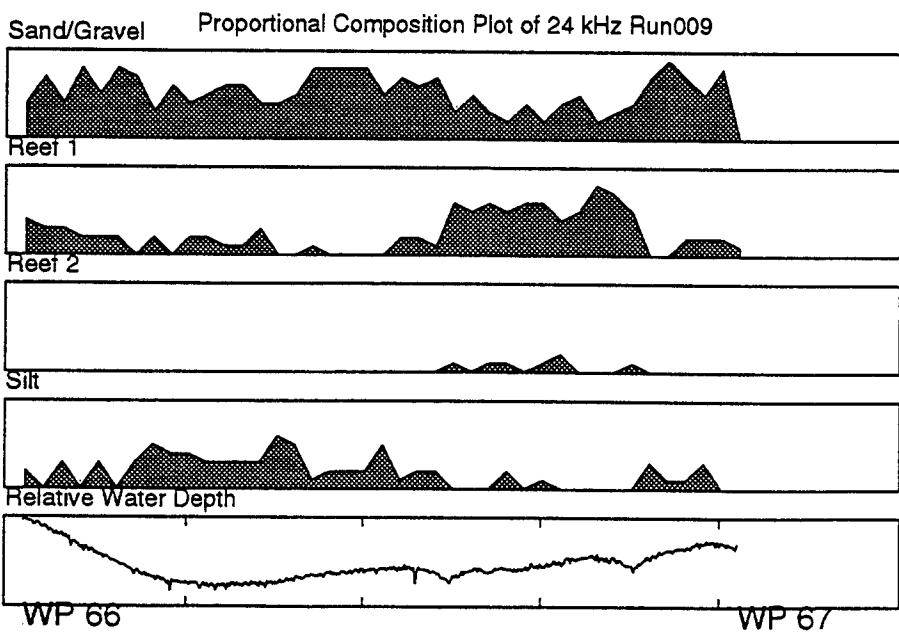
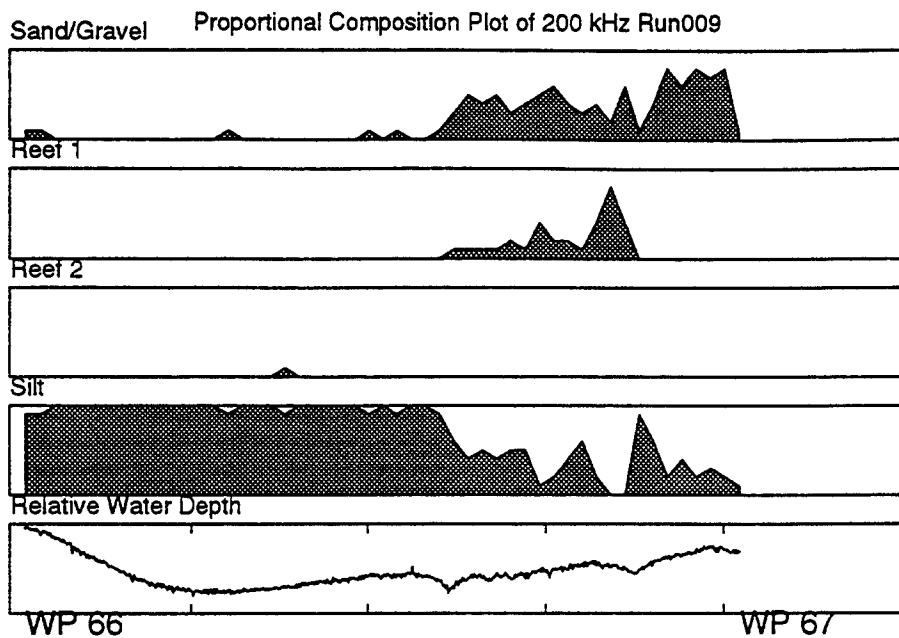


Figure B.10 WP 64 - WP 65.

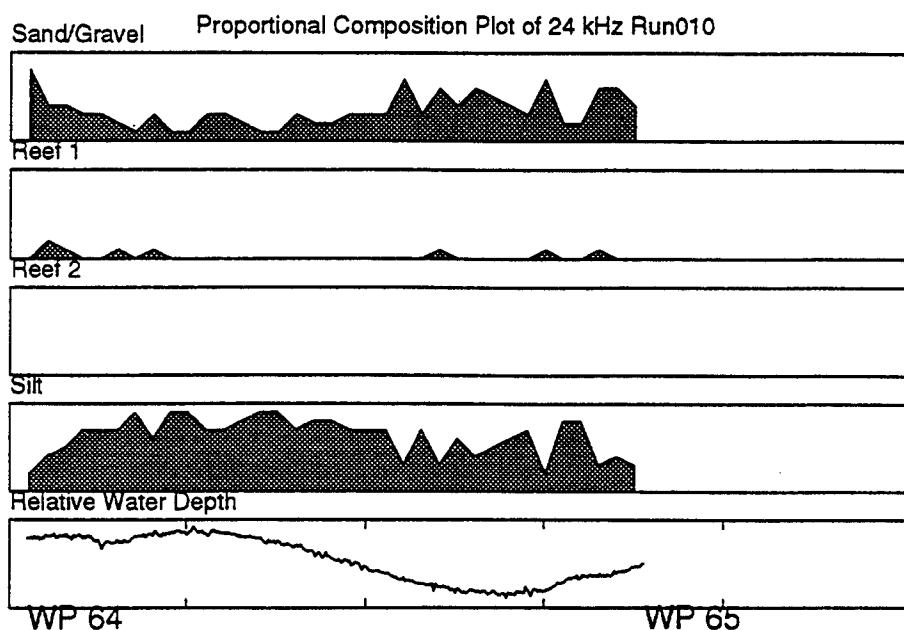
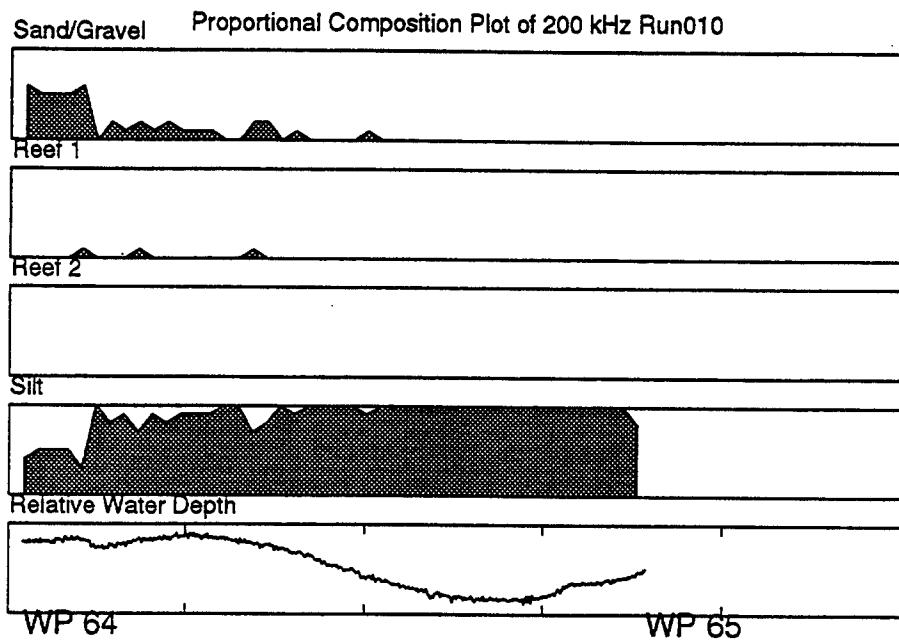


Figure B.11 WP 62 - WP 63.

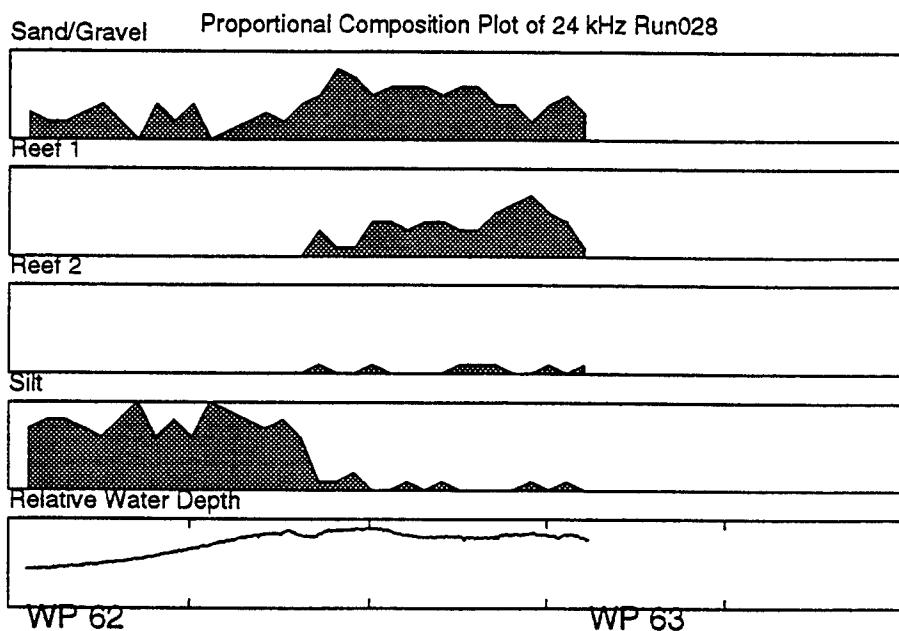
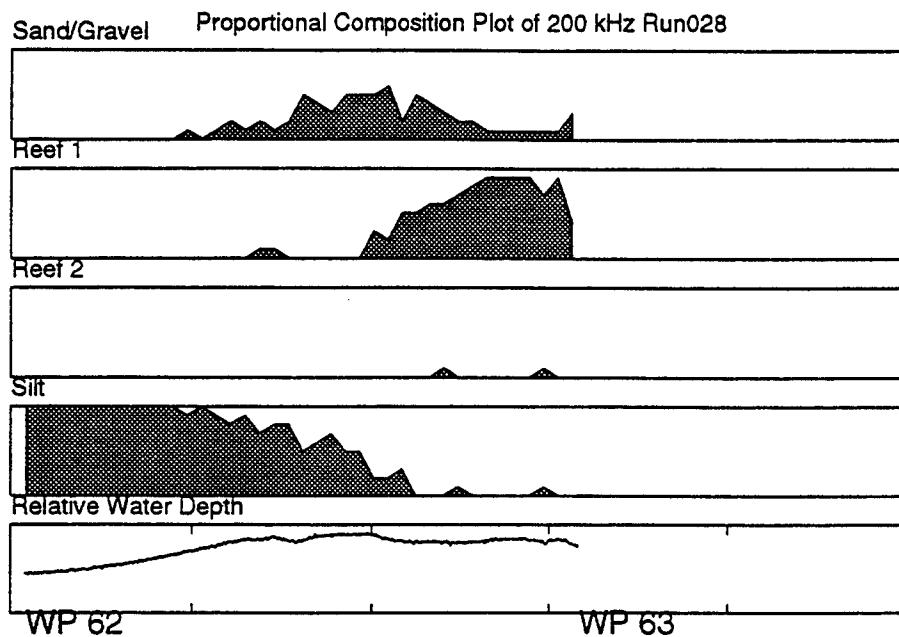


Figure B.12 WP 60 - WP 61.

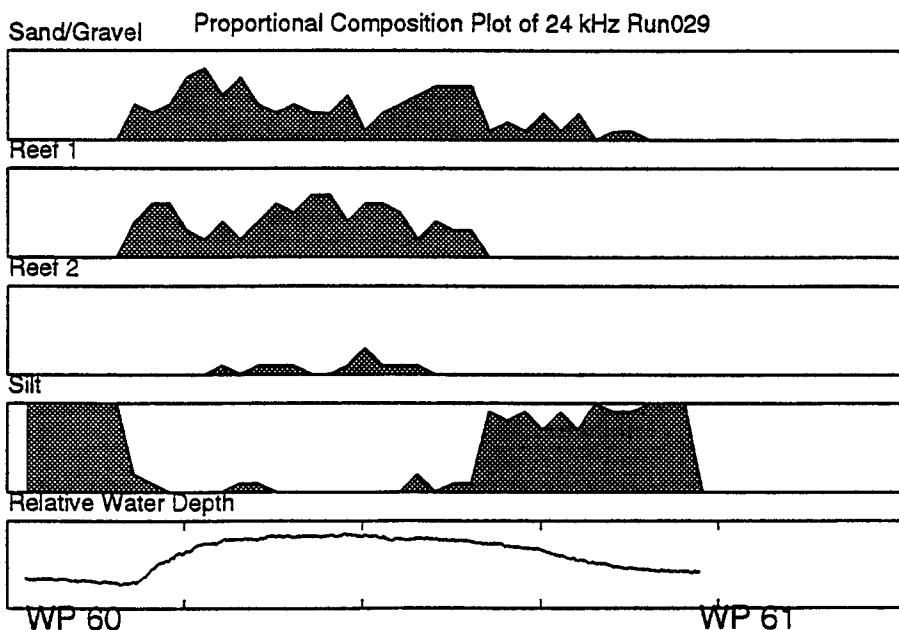
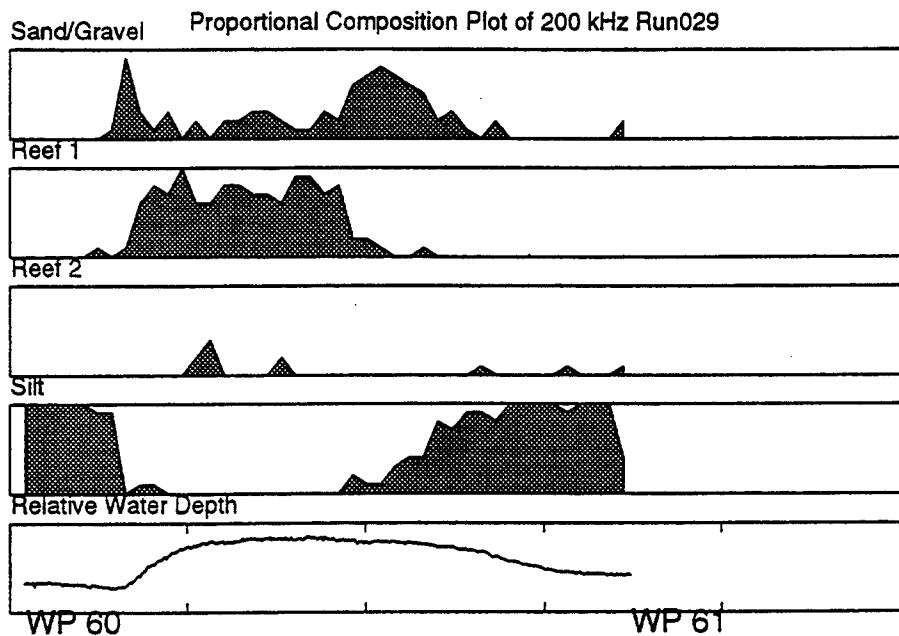


Figure B.13 WP 58 - WP 59.

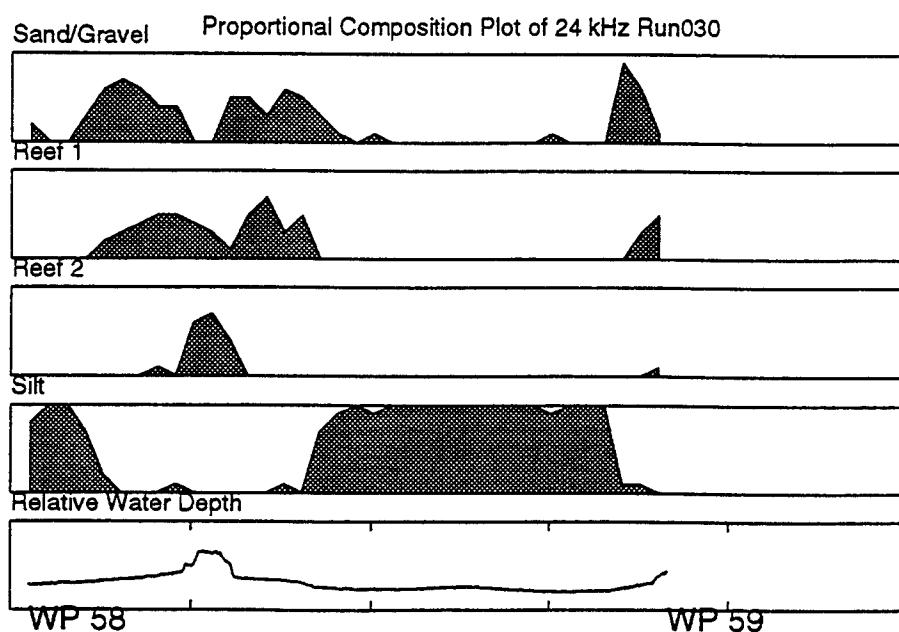
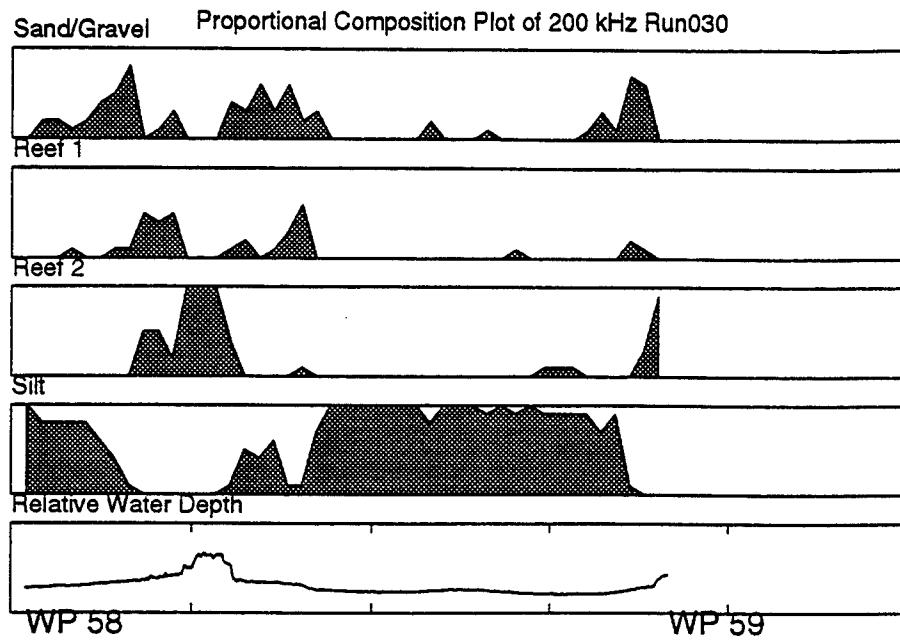
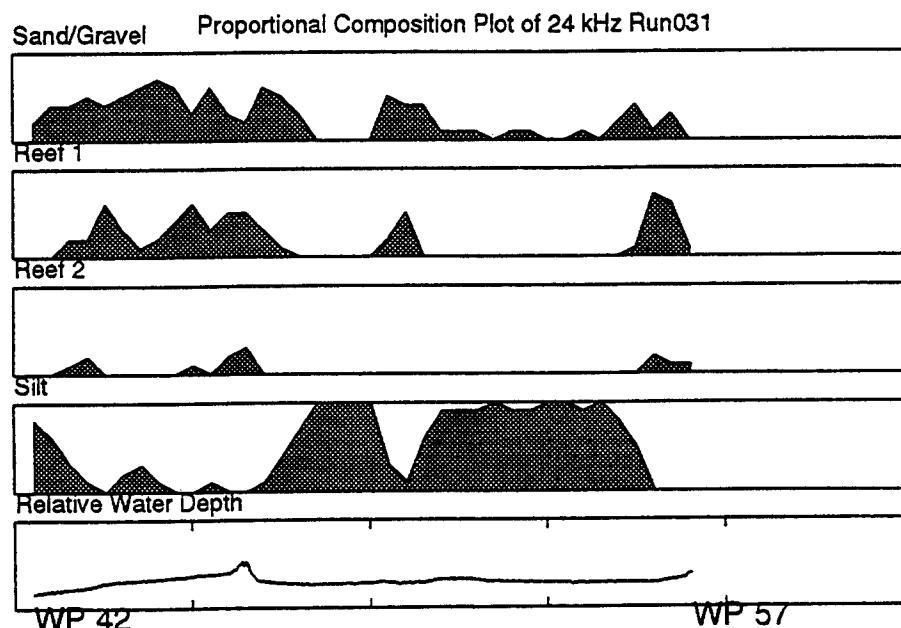
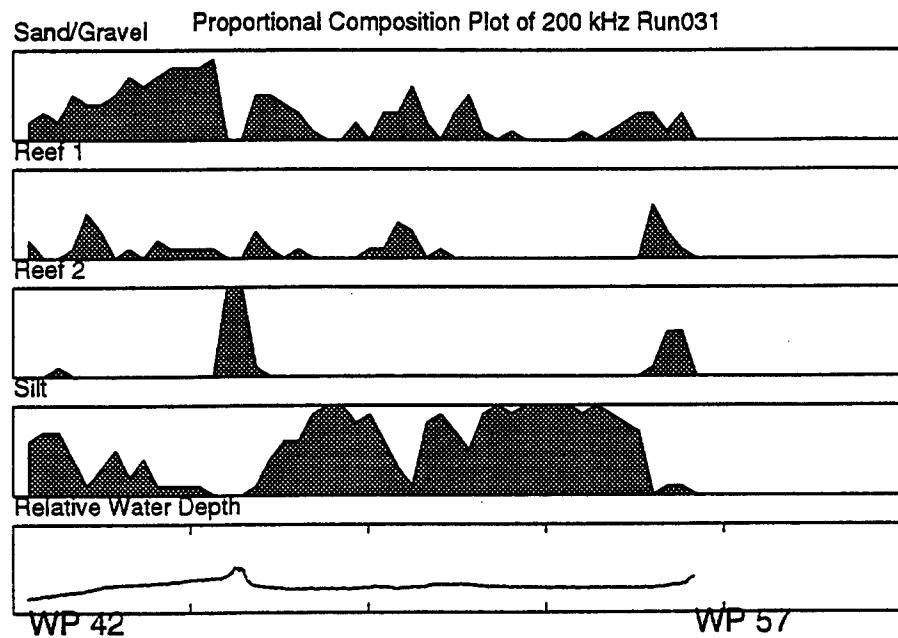


Figure B.14 WP 42 - WP 57.



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The research described in this report represents an important step forward in the development of seabed classification technology. First, it represents the application of the QTC VIEW technology to a new seabed environment. The data sets analyzed here involve reef seabeds which have not previously been studied. Second, they represent a consistent effort to compare the results obtained by using two different frequencies of sounder over the same seabed type. The results suggest that both 200 kHz and 24 kHz sounders can be used to classify the four bottom types involved in the study. However, it is clear that multispectral seabed classification holds significant potential in situations where, for example, a gravel bedform is overlain by a thin veneer of mud.

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